Multi-criteria risk analysis for large-scale photovoltaic power plants in Libya

Ahmed S. Kagilik[1*], Mustafa M. Sofia[2], Christian Bornhauser[3]

[1] as.kagilik@gmail.com, [2] m.sofia@asmarya.edu.ly, [3] christian.bornhauser@giz.de

[1]Department of Electrical and Electronic Engineering, Faculty of Engineering, Sabratha University, Libya

[2]Department of Mechanical Engineering, Faculty of Engineering, Al Asmarya University, Libya

[3]GIZ Gesellschaft für Internationale Zusammenarbeit, Berlin-Germany

*Corresponding author email: **as.kagilik@gmail.com**

ABSTRACT

Due to the virtually no experience with renewable energy large projects in Libya, the success of such projects is challenged by a multitude of risks. These are analyzed, categorized and quantified in this work. The methodology follows the "risk matrix" approach, by which each risk is defined by two attributes: the probability and the potential damage. Both were quantified by means of a simplified scoring scheme. The risks themselves are classified according to three temporal categories (planning phase, construction phase, operation phase) and six causal categories: management, engineering, administration/regulation, social acceptance, security threats and natural hazards. The analysis reveals that particularly shortcomings of project management and engineering capacities could endanger the success of the PV projects. Other important risks are emerging from unclear regulatory and administrative procedures. Likewise noteworthy are social acceptance risks and the difficult security situation in the country. The risk that natural hazards could substantially endanger the PV power plant projects is considered low. On basis of the risk analysis, the following recommendations for risk mitigation can be given: Highest priority has the improvement of the organizational capacities of relevant national authorities. These authorities must significantly enhance the quality of its internal organization to be capable to manage and organize the tendering, construction and operation/maintenance of PV power plants. For the first projects, it is recommended to hire external expertise in order to provide Libyan engineers with guidance for successfully carrying out international PV tenders. Furthermore regulatory barriers and authorization obstacles for PV power plants in Libya must be removed. Security problems remain an issue in Libya. Therefore, a professional security concept for the construction and maintenance phase to enhance trust of international contractors to participate in the projects should be established. On the other hand, the PV power plant projects also need a valid insurance concept in order to minimize the impact of the remaining risks of damaged due to theft, vandalism and natural hazards.

Keywords: photovoltaic power plants, project phases, risk analysis, risk categories.

1. Introduction

Libya, the country with the largest proven oil reserves in Africa, is also endowed with an enormous potential for renewable energies (RE). But despite excellent solar radiation, wind conditions and an abundant availability of undeveloped land, renewable options have never been seriously considered in the past. National energy strategies were primarily marked by efforts to develop the national hydrocarbon sector. Today, the new Libyan state is reconsidering its energy policies. Renewable energy sources are now seen as an important asset, in particular for the electricity sector, which is still entirely driven by fossil fuels [1]. Renewable power plants offer an opportunity to reduce the national consumption of domestic fossil fuel resources for electricity generation, thereby saving oil and natural gas for exports that are needed to sustain Libya's fragile economy in the country's ongoing political reconstruction and transition process. Libya has formulated its renewable energy aspirations in an ambitious National Renewable Energy Development Plan. The targets of this plan foresee a total share of 10 percent of electricity production from renewable energies by 2025 [2].

This present paper is a risk analysis dedicated to large-scale PV projects that are currently under implementation within the framework of the National Renewable Energy Plan. The reason for the present analysis was that during the planning process, a number of potential difficulties have been detected that could endanger the success of the PV projects in Libya. These risks have different origins (e.g. administrative, management, and technical risks; as well as security risks, economic and environmental risks) which could affect the projects at different implementation stages. To increase the awareness of the Libyan decision makers about these challenges and to provide them likewise with input for improvement and potential risk mitigation strategies, a multi-criteria risk analysis has been prepared. It should help to improve the conditions for large-scale PV power, prevent project failures, financial losses as well as delays in the country's efforts to fulfill its renewable energy targets. So far, there are only few studies dedicated to renewable energy project risks and they have analyzed the risk framework for renewable power projects in many regions, but only from an investor's perspective (private capital) and not - as required for the present study - from the perspective of a government authorities in Libya [3-6].

2. PV power plant projects in Libya

The photovoltaic program within the National Renewable Energy Development Plan is Libya's first attempt to install large-scale PV power plants in the country. So far, photovoltaic technology has only been applied in small scale off-grid systems, as well as in small number of grid-connected rooftop systems for demonstration purposes. Like most other North African countries, utility-scale PV power plants are at the moment an absolute novelty for Libya, for which neither the domestic industry, nor the national electricity authorities are sufficiently prepared. For this reason, the Libyan Ministry of Electricity and Renewable Energy decided to entrust the roll-out of the first projects to a specialized government bodies which received the mandate to investigate potential sites, launch an international call for tenders, and supervise the construction of some PV power plants by international contractors. With the launch of this PV program, the Libyan government pursues multiple objectives: 1) Maximizing revenues from energy exports, 2) Decreasing the internal consumption of domestic fossil fuel resources, 3) Improving energy security and stabilization of the energy system, 4) Developing competitive local RE industries [7].

Libya's experience with renewable power projects is still very low. The set-up of a specialized government agencies dedicated to these tasks is certainly a good move, but the agencies have just started to raise its competences and have so far only established few links to the international renewable energy community. The currently low level of experience therefore constitutes also a risk for the successful implementation of PV power plants in Libya. What renders the implementation of first projects furthermore difficult is a missing legal/regulatory framework for PV power plants in Libya. For instance, there exists no grid-code in Libya that would regulate the rules for the connection of renewable power systems to the national electricity network. Also with regards to other authorizations needed for the project implementation, the administrative circuits are not clearly defined by the Libyan authorities. Further obstacles might arise from legal claims and/or public opposition of the local population against the construction of PV power plants in their neighborhood.

The above-described challenges indicate that the success of the current PV projects is subject to a number of risks. This study attempts to provide a summary - and likewise a quantification - of these risks. Addressees of analysis are therefore in the first place Libyan decision makers and Libyan governmental organizations being in charge of executing the current projects. In the future, however, the methodology might prove also useful for other organizations, like for instance, development banks or private finance institutions, if the roll-out of the Libyan PV program-beyond the three PV plants-should shift away from a purely Libya-financed scheme and be shouldered also by other parties.

3. Risk Analysis

The risk analysis presented in this work has been tailored specifically to the current framework of the three photovoltaic power plant projects in Libya (north, South, center regions). The features of this framework suggest a categorization of the risks according to two dimensions: one temporal dimension, representing the project phases, and one dimension related to the origin of the risks. The evaluation methodology proposes a scoring scheme to quantify likelihood, as well as the severity of the impact of each risk. Final scores were attributed to each risk according to the scoring methodology.

3.1 Project Framework

For the three PV power plants, a Build-Operate-Transfer (BOT) project design is foreseen: A private contractor, selected by means of a tendering process, shall construct the plant and operate it during a 2-years guarantee period. After this period, the plant is handed over to governmental authority (REAoL, GECOL, etc..), which can decide whether it will carry out the operation and maintenance works on its own - or whether a subcontractor (private maintenance company) shall be hired. This BOT scheme is common practice in most public-sector financed PV power plant projects worldwide. The project flow illustrates that the whole project is classified according to three main categories (planning phase, construction phase, operation phase). At each of the three phases, the project is exposed to risks, which are in the following defined as (A) Planning risks, (B) Construction risks and (C) Operation risks.

3.2 Identification and definition of risks

While the project phases (Planning phase, Construction phase and Operation phase) determine the risks in their temporal dimension, there is also the causal risk dimension - defined by the actual nature of the risk or the source of the risk. For the present study about PV power plant projects in Libya, a set of 6 main causal risk categories was identified which are: I) management, II) engineering, III) administration/regulation, IV) social acceptance, V) security threats and VI) natural hazards. The outlined concept of categorization allows an arrangement of the risks in an array of two dimensions, as shown in figure 1. The temporal dimension provided by the different project stages (planning, construction, operation), and a causal dimension related to the different risk sources (management, regulatory, social acceptance, …).

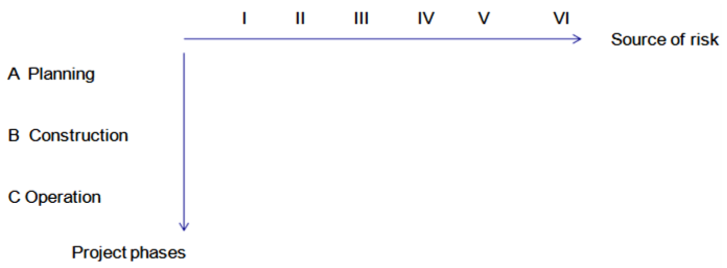

Figure. 1. Temporal (project phases) and causal (source) dimensions of risks

Following this logic, a more detailed elaboration of the risk categories for each project phase can be given as follows:.

3.2.1 Planning risks (A)

The central goal of the planning phase is to successfully perform a public, international tendering in order to find a high-quality EPC contractor for the construction works of the PV plant. Tendering PV power plants at international level requires experience (knowledge of tender procedures), management skills and some preparatory engineering (site visits, collection of data, feasibility studies, defining technical specifications, etc.) as well as administrative and communication efforts (obtaining authorizations, securing land and construction permits, informing the population/public stakeholders about the project).

3.2.2 Construction risks (B)

Central objective of the construction phase is to ensure the successful implementation of the PV power plant. This requires a careful supervision of the construction works of the EPC contractor. Throughout the entire construction process, the local authority must verify that the contractor respects the stipulations of the EPC contract. First and foremost, this concerns the technical requirements (usually verified by stepwise acceptance of construction milestones) but also the respect of social and environmental norms. Risks during construction of the plant can result particularly from an insufficient supervision of construction which might lead to failed milestones, project delays or, at the worst, that the plant is not fully functional. In addition, the currently poor security situation in Libya also poses a risk for the construction phase.

3.2.3 Operation risks (C)

The operation phase is actually divided in two stages: First, a two-year warranty period, in which the EPC (Engineering, Procurement, Construction) contractor must perform all maintenance and service obligations to maintain the PV plant in operation. This warranty period is necessary to ensure that potential defects will be remedied by the contractor himself. Operation risks of the PV power plant are becoming particularly important after the two-year warranty period. After this warranty period, the EPC contractor is relieved from these obligations, and the user himself becomes responsible for the operation and maintenance of the solar power plant.

3.3 Methodology

Strategies for minimizing risks can be classified into strategies to prevent and to response to risks. The initial strategy, risk prevention, is used in this study to develop an analytical framework which helps to identify and assess risk as well as to make decision makers in governmental organization aware about risks in an early stage of project development.

To analyze risks of large-scale PV power plants in Libya, the risk matrix concept is applied which has become very popular in project and risk management practice [8]. By using this concept, risks are differentiated according to their likelihood and consequences (potential damage), which finally provide important information to formulate risk minimization strategies [9]. As a detailed quantification of a potential PV power plant damage is difficult to carry out, a qualitative assessment is used that seems promising in the underlying study, although qualitative risk matrices rely on subjective interpretations. These may result in opposite ratings according to different users [8]. Nevertheless, as one of the main objectives of this study is to make decision makers in governmental institutions aware about existing risks, the risk matrix concept seems promising as it informs about the likelihood and consequences of risks in a very easy and comprehensive manner. The following five categories define the consequences (potential damage) used in this study in decreasing order of importance:

- **Catastrophic**: power plant project completely failed/PV plant fully damaged; no repair possibilities, power plant completely off-line (no power production) during operation.
- **Major**: power plant has major flaws, project heavily delayed, power plant can be established/repaired but only under high efforts and substantial additional costs, electricity production of the plant endangered/very low level.
- **Moderate**: functional but low quality power plant with possibility to remedy at additional costs, significant output losses.
- **Minor**: reduced but acceptable power plant quality. Project encounters minor problems and delays; additional project costs remain moderate. Output losses stay within acceptable limits.

- **Negligible**: power plant has only negligible flaws, minor delays, power plant performance (power output) meet the expectations.

These five categories are put into relation with the likelihood of risks. Also likelihood is identified in a qualitative way and subdivided into five categories ranging from high to low (almost certain, likely, possible, unlikely, rare). According to the relation of likelihood and consequences of risks within the matrix, risk combinations are classified into high, medium and low. In a second step, the qualitative risk matrix is translated into a numerical scheme which is particularly useful to overcome the still limited value of the qualitative matrix and to provide a more in detail assessment of risk likelihood/consequence ratios [10]. Both, likelihood and consequence categories, are rated from 1-5. Color codes, categorizing the resulting risks into four levels, make the classification more comprehensive. An overview of the final risk matrix is provided in Table 1. The different categories shall serve as a guidance for the planners and decision makers: “Highest risk” (more the 18 points in the rating and red color) requires urgent action for risk mitigation; “high risk” (between 12 and 18 points and brown color) likewise indicates that high mitigation efforts must be dedicated to this risk group. Less attention can be paid to the yellow, “Medium” category, while the “negligible risk” category (green) is not connected with any particular priority.

Table 1: *Risk matrix, quantification scheme and color code scheme*

	Catastrophic 5	Major 4	Moderate 3	Minor 2	Negligible 1
Almost Certain 5	Very high 25	Very high 20	High 15	Medium 10	Medium 5
Likely 4	Very high 20	High 16	High 12	Medium 8	Medium 4
Possible 3	High 15	High 12	Medium 9	Medium 6	Low 3
Unlikely 2	Medium 10	Medium 8	Medium 6	Low 4	Low 2
Rare 1	Medium 5	Medium 4	Low 3	Low 2	Low 1

3.4 Risk evaluation

The risk evaluation was carried out individually for each risk identified in the different project phases and risk categories. Thereby, each of the 35 singular risks (spread over the 3 project phases and 6 risk categories) received an individual rating for probability and damage - both on a scale from 1 to 5. The multiplication of these two numbers resulted in the final score. The attribution of the scores was performed in qualitative, but by considering expert opinions of Libyan stakeholders. For an easier, more graphical access, these results can be summarized in the form of web diagrams. In the planning phase, as shown in figure 2, the risks with the highest relevance, having a score of >18, are insufficient quality of tender documents, higher costs, contested tender. Looking at the origin of these risks it can be seen that they are mainly related to project management shortcomings. Risks of medium/high relevance (score 12-18) concern project delays, improper plant design, poor plant components, and budget cuts. Here, the risk causes are found mainly in the areas of engineering and regulation/administration. From the areas of social acceptance, security issues and natural hazards only risks of low or negligible relevance (score <12) can be expected: impact of natural hazards, resistance against the project and the risk of a cancellation of the project during the planning phase. In the construction phase, as shown in figure 3, there are no particular risks with the highest relevance (score >18 points) - but still many with medium/high importance: like in the planning phase, these risks concern shortcomings in project management and engineering: poor technical execution quality, construction delays, commissioning delays as well as the risk of increased construction costs. Furthermore, the issue of social acceptance (Resistance against the project) is getting more critical in the construction phase. Confronted with actual construction activities on the project site, the local population might become more inclined to oppose the PV power plant, which increases the risk for resistance against the project.

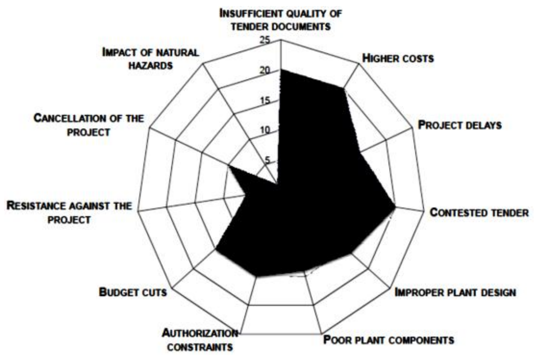

Figure 2: Risk assessment for the planning phase

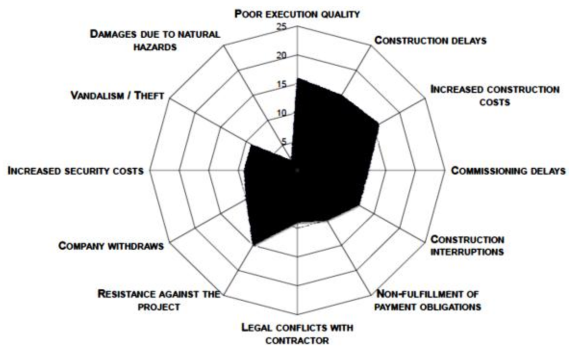

Figure 3: Risk assessment for the construction phase.

Administrative issues, in particular with regards to custom procedures, might also lead to a higher risk for construction interruptions. Minor relevance, because of the relatively short construction period, is attributed to the security-related risks: company withdrawal, increased security costs and vandalism and theft. Also the risk for legal conflicts with the contractor and non-fulfillment of payment obligations (due to budget problems) are not considered insurmountable. Negligible - also in the construction phase - is the risk of damages of the power plant due to natural hazards. The principal challenge in the operation phase is to maintain the technical quality and the power output of the PV plant over a period of 25 years. If is obvious that due to these requirements a completely different risk pattern comes to the fore, as shown in figure 4. Highly relevant risks that would severely endanger the power plant (risk level >18) do not occur - but there remain nevertheless risks of medium relevance touching the quality of maintenance, technical availability of the plant, power output reduction and degradation. The risk for the occurrence of vandalism and theft events, is also increased over the long timeline (25 years) of the operation phase. Risks of minor relevance are interrupted O&M services, resistance against the project, and lacking funds for maintenance. Also the risk for plant damages to natural hazard is considered low (3 points), although it is higher than in the previous project phases (1 and 0 points).

As can be observed, the significance of the risk categories depends on the actual project phase:

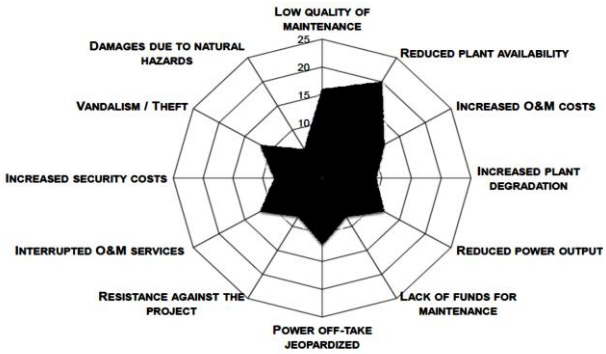

Figure 4: Risk assessment for the operation phase

- Risks due to management shortcomings are significant in all project phases, but are highest in the planning phase. Although the risk level decreases slightly in the construction and operation phase, the proper project management remains the concern for the success of the PV projects.
- Engineering risks are high during the planning and construction phase; but are less significant in the operation phase, where basically only maintenance works must be carried out.
- Regulatory risks are very important in the initial planning phase (when, for instance, the authorizations must be obtained), but become less important once the construction of the plant has started.
- Social acceptance problems are expected to reach a peak at the beginning of the construction phase when the local population is actually experiencing/realizing the execution of the project. During the planning phase, and during the 25-year operation period, social acceptance risks are generally low.
- Security issues remain at a constant, medium risk during all project phases.
- Natural hazard risks are negligible in the planning and construction phase, but slightly increase in the operation phase.

These findings already give first indications about the most essential risk mitigation strategies for the different project phases: In the planning phase, particular attention must be paid to management, engineering and regulatory aspects; in the construction phase, management and engineering likewise play an important role, but more emphasis should also be given to social acceptance issues. The operation phase likewise requires strong management efforts. In the next section, the individual risk mitigation strategies will be elaborated in more detail.

4. Risk mitigation strategies

The various mitigation strategies - broken down to the different project phases and risk categories - can be summarized in the following seven main recommendations.

4.1 Improve the organizational capacities

The internal capacities to manage photovoltaic power plants must be significantly improved in order to mitigate management and engineering risks. First and foremost, clear procedures must be developed to describe in detail how the PV power plant projects shall be carried out and which steps must be undertaken by any staff members in order to successfully perform each project phase:

- Development of an internal "project manual" describing all processes are needed in order to carry out the project. The manual shall include flow diagrams and manning schedules for all project phases in order to allow an assessment for the need of human resources and in order to detect potential bottlenecks where the skills are currently not sufficient and external support is necessary.
- Definition and description of all tasks and engineering procedures that must be carried in each project phase:
  - Planning phase: site selection, collection of the necessary authorizations, feasibility studies, grid studies, soil study, definition of technical ToR, tender evaluation procedures, norms and standards.
  - Construction phase: procedures for construction supervision and commissioning procedures.
  - Operation phase: procedures for operation supervision, definition of maintenance programs, monitoring
- Set-up of an internal document management system at any authority.
- Acquisition of the necessary tools, such as software (solar simulation software, project management software), equipment for testing and commissioning (IV-curve measuring devices, IR-cameras etc.)

The definition of the procedures in the "project manual" shall also help to assess the authority needs in terms of human resources:

- Definition of the skills needed for managing the PV power plant program.
- Drafting an organization chart defining the responsibilities of the involved personnel.
- If required: hiring of new staff members

If it becomes obvious that the current skills and capacities are not sufficient for the tasks described in the “project manual”, additional trainings and/or the help of international experts may become necessary.

4.2 Hiring of external experts

It is common practice on worldwide level, that large engineering projects in the power sector are accompanied by external/international consultants. This also concerns renewable technologies - in particular if it is the first time for a country to build these power plants and the experience with such projects is generally low. At least for the first tender projects, it is therefore recommended that external experts must be hired for:

- assistance in the drafting of tender documents
- tender evaluation, contract award
- owner’s engineering (OE) services during the plant construction phase including commissioning
- supervising the quality of the O&M services during the guarantee period.

Moreover, external experts shall provide trainings to Libyan staff members, in order to make the agency fit for carrying out future PV projects on its own.

4.3 Management of regulatory issues and authorizations

The unclear situation in terms of regulatory and administrative procedures (permits, authorizations) is a substantial issue for the PV power plant projects. It should be proactively faced by the authority:

- The authority should start with an assessment of all authorizations / regulatory provisions being potentially relevant for PV power plant projects. External legal advisors, if needed, could carry out this evaluation.
- The authority should - on political level - advocate a clear legal framework for renewable power projects in the country.
- The grid codes that defines clear conditions for the technical connection of the renewable power plant to the national electricity grid and the conditions for the off-take of the produced electricity and the dispatching of the PV power plant should be defined. In addition to that, more efforts to ease the customs procedures for the contractor to import solar power equipment should be undertaken.

4.4 Proactive attitude to increase social acceptance

If social acceptance issues are not appropriately considered, they can substantially obstruct the smooth roll-out of the projects. Different levels to avoid potential resistance against the projects can be acted:

- Increase the communication about the project: inform the concerned population at early stage about the impact and consequences of the project.
- Carry out stakeholder workshops, involve local authorities, industry and decision makers.
- Ensure that the construction company behaves properly during the construction phase, e.g. by minimizing environmental impact, avoiding excessive water consumption and waste.
- Develop strategies how the value generation for the Libyan industry, including the creation of jobs could be increased (e.g. local content provisions in tender design).

4.5 Security concept

It is obvious that the current country-wide security problems must be regarded as a risk of force majeure, with active mitigation possibilities being beyond the power of the authority. Nevertheless, on the micro-level, certain measures can be undertaken to limit the risk of personal injuries and property damage during the power plants' construction and operation phase. For each project, an individual security concept should be developed - in close cooperation with the EPC contractor, the local authorities and security bodies. It is mentioned that currently many international companies require such security concepts before they are able to send out their engineers or other personnel to Libya.

For the operation phase, the security concept should foresee technical measures (camera surveillance, protected fence, …) as well as services of professional security companies, in order to avoid theft and vandalism.

4.6 Financial planning

In order to avoid that budget problems lead to project interruptions, a concise financial plan for the project has to be established, considering the financing internal structures at the authority, as well as the project costs (e.g. payment schedules for the construction works of the contractor). A binding financing commitment has to be obtained by the public (or private) financiers.

4.7 Insurance concept

Sufficient insurance provisions - against natural hazards, possibly also against theft and vandalism - should be foreseen for the construction and the operation phase.

5 Conclusions

In a move to render the Libyan electricity generation more diverse and more sustainable, the new Libyan government recently decided a National Renewable Energy strategy. Due to the particular situation of Libya with virtually no experience with renewable energy projects - the success of the projects is, despite the strong commitment of the government, challenged by a multitude of risks. This work sets out to analyze and quantify these risks, and likewise gives recommendations for their mitigation. The methodology followed in the analysis basically rests on Nohl's "risk matrix" approach, by which each risk is defined by two attributes: the probability and the potential damage. Both were quantified by means of a simplified scoring scheme. The risks themselves are classified according to 3 temporal categories (planning phase, construction phase, operation phase) and 6 causal categories: management, engineering, administration/regulation, social acceptance, security threats and natural hazards. In consequence, an overall set of 18 risk groups was quantified with scores - and summarized in the overview tables. The analysis reveals that particularly shortcomings of project management and engineering capacities could endanger the success of the PV projects. Other important risks are emerging from unclear regulatory and administrative procedures, for example due to a missing grid code for the connection of renewable power plants to the electricity network. Likewise noteworthy are social acceptance risks and the difficult security situation in the country. The risk that natural hazards could substantially endanger the PV power plant projects is considered low. Having analyzed and quantified the different risks, the study concludes with set of recommendations for risk mitigation. By respecting these recommendations the overall risk for severe project failures should be significantly minimized. It is noted that the recommendations are also valid for other renewable power projects in Libya - and could therefore principally also be applied to wind farms or CSP projects.

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