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Water–Energy–Food Nexus Assessment of Solar Energy Farming Interactions

The Azraq Case in Jordan with Insights from India

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LIST OF ABBREVIATIONS

ACCWaM	Adaptation to Climate Change in the Water Sector in the MENA Region
EDCO	Electricity Distribution Company
FIT	Feed-in tariffs
GCC	Gulf Council Cooperation
GIZ	Gesellschaft für Internationale Zusammenarbeit
HWF	Highland Water Forum
IRENA	International Renewable Energy Agency
MEMR	Ministry of Energy and Mineral Resources
MENA	Middle East and North African
MNRE	Ministry of New and Renewable Energy
MoA	Ministry of Agriculture
MoE	Ministry of the Environment
MWI	Ministry of Water and Irrigation
PPA	Power purchase agreements
PV	Photovoltaic
SEF	Solar energy farming
SEF Azraq	The Azraq Basin (Jordan) solar farming SEF pilot project
SPICE	Solar Pump Irrigators' Cooperative Enterprise
SPIS	Solar-powered irrigation system
The nexus	The water–energy–food nexus

1 INTRODUCTION TO THE REPORT

1. INTRODUCTION TO THE REPORT

This report focuses on experiences with solar energy farming (SEF), and in particular the solar energy farming project in the Azraq basin in Jordan (referred to as SEF Azraq). SEF Azraq sought to encourage farmers to substitute farming with livelihoods as solar farmers. This report aims at generating relevant recommendations for the implementation of SEF projects in Jordan and the Arab region by integrating lessons learnt from SEF Azraq, insights from a water–energy–food nexus (referred to as nexus) assessment, and experiences from international cases on SEF, particularly in India. In this sense, the analysis in this report is carried out in four main parts: a) a SEF nexus assessment; b) an in-depth analysis of SEF Azraq; c) a presentation of international SEF experiences with a special focus on India; and d) lessons learnt and illustration of options for enhancing SEF in Jordan and the region.

Chapter 3 introduces and conceptualises SEF in order to provide a basis for understanding further analyses and the overall dissemination and contributions of SEF. It also relates SEF to water, energy and food resource uses and potentials. In part 3.1, the term *SEF* is defined and conceptualised as a broad term that encompasses the SEF Azraq idea as well as others. Different SEF applications and primary objectives are explained in the context of the nexus. Part 3.2. explains the driving factors behind SEF projects, while part 3.3 provides a first look at some common SEF applications, and explains the factors for the feasibility and cost–benefit relationship in SEF projects.

Chapter 4 presents a nexus assessment and explains the overall nexus relevance of the SEF idea by highlighting the trade-offs and synergies as well as the contribution of SEF to achieving water, energy, and food securities (Part 4.2). In Parts 4.2 and 4.3 the relevance of SEF in the Arab and Jordanian contexts respectively is discussed.

Chapter 5 analyses SEF Azraq by introducing the project idea and history (Part 5.1) and conducting a detailed stakeholder and issue analysis in order to explain power asymmetries, interests, and participation modes (Part 5.2). Part 5.3 provides an evaluation of the critical links and policies in the SEF Azraq project by elaborating missing links inherent in the project design and the project's context. It also provides an overview of opportunities for reform.

Chapter 6 presents the Indian case for SEF. It highlights several selected projects that are relevant to the idea of SEF Azraq. Recent and innovative projects and public programmes from different states are included. These selected examples either include an option for farmers to sell surplus power, or innovatively link SEF to the goal of reducing water abstractions (Parts 6.1 and 6.2). The overall Indian SEF experience is discussed and compared with that of Jordan (6.3).

Chapter 7 develops both technical and non-technical (institutional or policy-related) options that are available for the design of SEF. It explains the advantages and disadvantages of each option. These options represent a state-of-the-art overview based on international practices and innovations on key conceptual design categories relevant for SEF (Parts 7.1 and 7.2). Part 7.3 develops an integrated analysis that illustrates how the advantages and disadvantages are analysed in the search for an optimal design of SEF projects. It illustrates this using the example of SEF Azraq, and discusses the optimal future design set-up for Jordan.

Chapter 8 provides insights into SEF for the Jordan and the Arab region based on knowledge from comparative analysis of SEF projects. Such insights are largely not determined by sociopolitical contexts, and have general relevance for future projects in the region.

Chapter 9 integrates knowledge from previous chapters into a proposed cycle for SEF conception and implementation, as well as final recommendations.

Chapter 10 discusses lessons learnt from the analysis in the report, while the final summary is provided in Chapter 11.

2

REPORT HIGHLIGHTS

2. REPORT HIGHLIGHTS

2.1 How is the term Solar Energy Farming (SEF) used in this report?

There is no exclusive or common use of the term *Solar Energy Farming* (SEF). As such, it can be found when describing any given solar farming activity or referring to solar farms on any type of land, and for various uses. The examined project in this report, the SEF Azraq project, uses the term in reference to a stand-alone system that incites farmers to substitute traditional farming activities with farming and selling of solar energy. The overall aim is to reduce agricultural activities in the Azraq basin and thus decrease the use of vulnerable groundwater resources. However, SEF in this report is based on a broader definition than that in SEF Azraq. The report uses SEF to describe any agri-voltaic land utilisation system, thus essentially broadening the definition of SEF to solar energy applications on used arable land, or the conversion of used arable land for solar energy production. In this sense, stand-alone systems that do not seek to combine solar energy use with agricultural and water use issues (*e.g.* the pilot project, SEF Azraq) as well as combined systems linking solar energy use with traditional farming and irrigation practices are examined (*e.g.* dual systems, solar irrigation systems, solar pumps). SEF is thus used to describe the broad range of combinations of arable land use with solar energy production use, while *SEF Azraq* is used to refer to the analysed project idea of using solar energy as an alternative income for farmers in the Azraq basin.

While the project uses SEF in a broad sense to describe agri-voltaic land utilisation systems, the focus is on those ones with a power-purchase agreement. This is the case with the stand-alone idea of the SEF Azraq, as well as some of the reported projects in India, USA, Canada, or Japan. Projects aiming at agricultural modernisation without a power purchase agreement are contrasted with newer ones that advance this option. Although not the focus of this report, projects not having this option represent precedents to the new projects with this option. Furthermore, any SEF project can be theoretically enhanced with such power-purchase options in the future. They are therefore included in the report, and also covered by the used definition of the SEF term.

2.2 Why should SEF be defined in a broader sense?

While the Azraq project's main aim is to reduce water abstractions through substituting agricultural livelihoods with livelihoods as solar farmers, some other projects analysed from international cases might include the same aim indirectly, or as one of several others. At the same time, other projects show a diversity of implementation approaches and do not exclude linkages to agricultural activities or water-use issues. This report uses SEF as a broad and overarching term to describe all of these projects, although they are often separate in their design, intent and motivation. However, if these projects include a power purchase agreement, they become quite interrelated. With a power purchase agreement, the borders separating many projects on farmers' use of solar energy can disappear. The reason for broadening the definition of SEF beyond the SEF Azraq use of the term is thus so that other SEF projects with a power purchase agreement cannot be separated from conceptual and practical terms. The following points illustrate this difficulty:

No separation based on certain farmers' choices.

> *The different projects have farmers (agents) and solar energy applications (technology) in common. Agents have the choice of using technologies for different purposes or combining their uses. If one defines SEF as the farmers' choice to exclusively use the technology for a specific use, e.g. only for the sale of solar power, no separation can be established between SEF Azraq and other projects. For example, if an adequate tariff exists, farmers can change the use purpose anytime and sell solar energy instead of using it on-farm, regardless of the intentions of the specific type of project.*

No separation based on certain change processes.

> *One could define SEF as cases where farmers changed their livelihoods from traditional farming to solar-energy farming. However, such a definition cannot be confined to any specific project. In facts, farmers can decide this in any project set-up, and even without a specific project; e.g. in the pursuit of better income opportunities.*

No separation based on certain project types.

> *The SEF Azraq project advances the use of solar systems to replace agricultural activities with solar energy use restricted for sale. Using this project type to define SEF cannot separate SEF Azraq from other types of projects where such restricted use can evolve over time. For example, with a power purchase option, a project focusing on solar use for pumping or irrigation can lead to farmers exclusively or partially selling their produced solar energy. Moreover, solar pumps provided by a modernisation project can later be net-metered when farmers decide to sell all of their produced power.*

2.3 What is special about SEF in the Jordanian case of Azraq?

The SEF Azraq project entails an ambitious objective of substituting a part of the water-intensive and unsustainable agricultural activities with more profitable livelihoods for farmers as solar farmers. The prerequisite for this is that farmers are given a power purchase option. The project sought to install a pilot solar application to demonstrate technical and economic feasibility, which was studied beforehand and judged positively. The assumption here is that farmers, when provided with a better income opportunity, will convert from traditional farming to solar farming, and hence water abstractions will decrease. In this sense, the project does not target improvements in agriculture, irrigation, or on-farm solar energy use, nor does it involve activities related to these sectors. This direct focus on using solar energy as a stand-alone system to reduce water use by abandoning agricultural activities represents a rather unique example of combining solar energy, water, and agriculture. The project idea was developed through a participatory process in the basin stakeholder forum, and was later promoted by the water ministry, together with donors. Using this approach, the project represents one of the first SEF projects in Jordan and the wider Arab region.

2.4 What is the difference between SEF in Jordan and other international experiences?

Solar energy applications in agriculture have been around for a couple of decades, and were led by the energy and agricultural sectors as a way to promote the use of renewable energies and improve the livelihoods of farmers. SEF in a broader sense as understood in this report can include solar pumps, solar-powered irrigation systems (SPISs) or dual systems of solar energy production and agriculture on the same land plot. Some of these applications presented in this report have recently been combined with a power purchase. The key differences are therefore as follows:

Project legacies.

Other international experiences highlighted in this report are often older and developed out of agricultural modernisation projects to incorporate power purchase options. For example, SPIS systems evolved to be combined with feed-in tariff in India, while newer public programmes have only recently incorporated water use issues alongside objectives on renewables promotion and improving agricultural productivity.

Leadership.

The energy sector led older SEF projects, with a strong participation by the agricultural sector. Newer programmes are involving stronger participation modes of water-sector stakeholders, while leadership remains largely the energy and agriculture sectors. In contrast, in the SEF Azraq, participation of the energy and agricultural sectors is less strong.

Integration.

The international SEF cases presented have more direct links between agricultural activities, water use, and solar energy. This means linking solar energy use to irrigation practices, providing solar irrigation and pumping technologies, or linking subsidies to improved on-farm practices. At the same time, sale of surplus power is incentivised through different measures. In contrast, solar energy production in SEF Azraq is up front restricted to sale.

2.5 Why are international project experiences relevant?

Since the separating line between Azraq SEF and other highlighted projects is related to project motivation and design (methods used), these projects interact and interrelate in many aspects, *e.g.* aims, short- and long-term impacts, development contexts, *etc.* International experiences can provide valuable insights for alternative technological options, involved trade-offs, participation modes, financing and subsidisation options, and success factors. This report highlights in Chapter 7 several technical as well as policy and institutional design options based on international experiences in order to provide directions for updating SEF in Jordan or in other cases. Decisions on the right options should be made using an integrated analysis based on clear objectives as highlighted in Chapter 8, and embedded in a participatory process as highlighted in Chapter 9. In this sense, international experiences can significantly help in addressing the issues of optimal design and specificity of interventions in future projects.

2.6 Are there cases where traditional farmers switched to become solar farmers?

Yes. Traditional farmers have partially or completely changed their livelihood to become solar farmers. This is especially the case in the context of renewables policies in developed countries that allocate high incentives such as high, fixed power-purchase tariffs. Furthermore, farmers who face low profits and rising costs can buy a plant in order to supplement their income or reduce their on-farm energy costs. These cases are rarely related to specific SEF projects or programmes targeting agriculture. Moreover, they represent additional income opportunities that are provided by changing energy economics in a country, which pushes to establish renewables. In this case, the decisions of farmers are not stable. If the power-purchase tariff declines, farmers can switch back to traditional farming and dedicate their produced energy to productive on-farm uses.

2.7 Why should the water–energy–food nexus assessment be applied to SEF in a broad sense?

The water–energy–food nexus (shortened to *the nexus*) assessment delivers more insights and comparative lessons if applied to SEF in a broader sense, *i.e.* beyond the project focus of SEF Azraq. The contribution of the implementation of SEF Azraq to the resources securities is clear and does not allow further conceptualisations or much analysis: an increase in energy security (positive effect) through a decrease in water abstractions (positive effect), and a decrease in unsustainable agricultural activities (positive effect). If implemented, these benefits of SEF Azraq entail various positive spill-overs, as described in Parts 4.4 and 5.1. A highly productive nexus assessment is achieved if SEF is not confined to a location and a specific design. In this case, rich analyses can be generated by looking at SEF in variations of location and design. The location determines the resource potentials and current resource uses, and hence the primary objective of SEF applications (Part 4.1). The design of a SEF project determines the anticipated changes in resource-use patterns (Part 5.1). Therefore, looking at the impacts of water, energy, and food production from different environmental contexts and project designs provides a better appreciation of SEF as a nexus idea. Understanding SEF as a broad term enriches SEF Azraq and provides insights into applicability in other areas. For example, SEF in countries such as Sudan might be less oriented towards water-saving objectives such as those in Jordan, and thus less attractive for the substitution idea of SEF Azraq. Furthermore, the same water impacts of Azraq SEF in Jordan (increased energy with reduced water and agricultural use) can be found in the controversial case in Canada through a different project design. Moreover, the ambitious contributions of Azraq SEF can be compared to the impacts of less promising approaches of solar pumping promotion which might lead to water overuse problems, *e.g.* in arid and/or water-scarce areas.

2.8 What were the outcomes of SEF in Jordan?

SEF Azraq promoted the idea of substituting agricultural livelihoods with livelihoods as solar farmers in the Azraq basin. For this, several workshops were held and reports issued, including a technical feasibility study showing the higher profitability of solar farming in comparison to income from traditional farming. A pilot project was conceived, an initial farmer selection conducted, and a financing scheme outlined. However, the project ended with no pilot plan due to multiple implementation difficulties. No agreement on the power purchase option, and the lack of participation from farmers and energy stakeholders, were key causes of the project not moving forward (see Chapter 5).

2.9 What were the outcomes of similar international experiences?

SEF projects with no power purchase option vary a lot in their design and legacies. It has been argued that the promotion of solar energy in agriculture has led to increasing water abstractions in cases such as India due the availability of a cheap energy source for farmers. In such a case, solar pumping with no improved water use practices holds important risks and differs significantly from the SEF Jordan idea, integrated SEF projects with water-use regulations and/or SEF projects with PPA. More recent projects therefore link SEF with improved irrigation, or condition solar energy subsidies on the instalment of water-efficient irrigation and pumping technologies. In this way, water use reductions might be achieved together with increased use of renewables in agriculture. Other new SEF projects combine SEF with power purchase agreements (PPAs). SEFs with a PPA also vary from net-metering solar pumps, establishment of solar farming cooperatives, connecting SPISs to the grid, developing solar farms as pay-as-you-go systems, *etc.* Such projects are more related to SEF Azraq as they can lead to a partial or total substitution of agricultural activities through solar farming. However, in contrast to SEF Azraq, solar energy production can be used on-farm or sold to the grid. Attractive feed-in tariffs (FITs) are provided to encourage the sale of power. Results from such approaches are promising, although projects are still growing and are sometimes criticised for over-subsidisation and lack of effective control mechanisms. There are not enough well-documented cases to prove that these projects have led to long-term substitution of agricultural activities with solar farming.

2.10 What were the key problems in the Jordanian case?

There were many difficulties in implementing the idea behind Azraq SEF, which can be summarised as follows (with a more detailed analysis in Part 5).

Ambitious long-term impact in the implementation approach.

The shift of farmers' livelihoods into solar farming is difficult to induce through a project, as it is often a result of many push-and-pull factors that, in the long run, lead to abandoning one employment to another one in another sector. This long-term impact is difficult to achieve merely through the provision of technical approaches (provision of solar farms), or the indication of profitability advantages (economic feasibility for farmers). Inducing such a shift as a project's method in order to achieve water savings is quite ambitious, *and difficult to achieve on a large scale. The SEF Azraq project sought to give directions by piloting such change on a small scale; however, necessary push factors were not yet there. For example, while land productivity and profitability are beginning to decrease in the Azraq case (disincentives), other agricultural incentives remain, such as high energy and water subsidies as well as hidden incentives through illegal land use. Another example, increased mobility of famers (e.g. capacity, education, affluence) can push farmers to pursue employment in other sectors. However, this mobility is low in the Azraq case, and has not been enhanced through capacity building or training. More importantly, key pull factors in the sector of solar farming were little manifested. The following pull factors were missing: low transaction costs (e.g. transparent information on how to change to the new sector), attractive financing mechanisms for businesses, a stable profitability outlook, and low entrepreneurial risks, etc. In fact, recent projects for India, for example, demonstrate that a partial livelihood transformation can result in the short term as farmers decide to gradually supplement their income with solar farming. Often, these projects regard such transformation as an impact of an intervention linking on-farm solar energy use to a power purchase agreement. In addition, international experiences from industrial countries show that farmers can voluntarily shift to solar farming in pursuit of better profitability as a result of a high FIT. However, these decisions seem unstable and reversible upon changes of the FIT. Overall, for a long-term livelihood transformation, it would require the availability of a range of push and pull factors that are very difficult to influence through single projects or analytically addresses in full.*

Dominance of water concerns.

The SEF Azraq project aims at alleviating water abstraction concerns by making some farming "disappear": i.e. replaced with solar farming. In this light, farmers become energy entrepreneurs, agricultural land use is reduced, and the main concern of the water sector, namely water abstractions, is accommodated. SEF Azraq deliberately avoids linking SEF activities with land and water use, or providing farmers with options for the use of solar energy, e.g. on-farm use vs sale. Furthermore, participation modes of agricultural and energy sectors, as well as farmers, were relatively weak in comparison to other SEF projects with a power purchase option. Convincing strategies for these actors are not well developed, and where restricted by the project, focus on replacing "farmers" with "solar farmers".

Contextual impediments.

SEF in the Jordanian context represents a novel approach that may face many difficulties in the short run. Firstly, it requires strong communication and collaboration mechanisms between relevant nexus sectors. Such mechanisms do not exist in Jordan, and would need time to develop. Secondly, the current renewable energy policies are less oriented towards social considerations or small-scale projects. Thirdly, agricultural interests have a prominent political role, and are oriented towards the protection of the status quo of land development using cheap water and energy.

2.11 What can Jordan learn from international experiences?

There are many lessons for Jordan that can be drawn from international experiences and are addressed in this report (see Parts 7 and 8). Some key lessons relate to the importance of the following issues: balancing technical and policy design options in the project; considering combined systems alongside stand-alone systems; empowering agricultural and energy stakeholders in project leadership; incorporating concern issues of the energy and agricultural sectors; incorporating farmers' realities through non-technical feasibility studies and detailed farm analyses; providing reasonable incentives in terms of SEF subsidisation; working more closely with farmers; and expanding the scope of SEF projects in order to address financing and profitability risks. Overall, international experiences do not provide a golden path for SEF implementation. Instead, they show the importance of developing an integrated perspective in the design of SEF projects that links the concerns of different sectors and carefully weights different options.

2.12 How can SEF in Jordan be improved?

Improvement in the application of SEF in Jordan is needed and worthwhile. The lessons from international approaches provide important directions for improvements of SEF in Jordan. Other opportunities are mentioned in Part 5.3, both under the current arrangements and under a scenario of future reforms. In order to summarise the key messages with regard to improvements, it is important to understand that such improvements should address both the project's context and its design. The project success cannot be significantly improved if enhancement of the project design is quite unrealistic for the context, or if the context is too obstructive for an otherwise realistic idea. The following descriptions explain why a middle-path scenario is the best approach for improvements.

"Perfect world" scenario.

A project idea can be unrealistic given the changes required in the project's context in order to make it feasible. For example, it is arguably fruitless to pursue improvement suggestions that address overarching issues related to developmental and political contexts as a way to improve the project's feasibility, as this would mean constructing a perfect world to fit an essentially unrealistic idea. In the SEF Azraq context, these issues would include addressing distortions through water and energy prices; eliminating illegal water and land use; breaking up the dominance of agricultural interests; solving sectoral discoordination and conflicts; reforming renewables regulations or policies; and radically improving farmers' affluence and mobility. These issues can make the project more feasible, but represent overarching developmental challenges that are basically beyond the reach of single SEF projects; although, in the long term, successful projects can contribute to addressing them.

"Perfect technology" scenario.

An overemphasis on technological solutions to improve the project idea without having a conducive context will not improve the outcomes. Here, it is fruitless to suggest improvements to the project idea or the technology used without having minimal requirements in the project's context to support implementation. This would mean seeking a perfect technology in an imperfect context. In the SEF Azraq example, no matter of how many changes are applied to the project, there are certain prerequisites. These include strong participation of farmers, agricultural stakeholders, and energy stakeholders;

the availability of an adequate FIT and some form of capital cost subsidisation; measures to improve farmers' capacities; some form of coordination among stakeholders; and the ability to condition the subsidisation.

"Middle path" scenario.

The best approach to improving the project is through a middle-path scenario in which the project's idea evolves to be more context-specific, while some changes in the contexts are sought and induced. Recommendations in this report follow this approach and provide directions for incremental changes in the design and context of the projects; for example, developing convincing strategies, analysing welfare contributions, balancing project participation mechanisms, addressing financial risks, establishing ad hoc coordination mechanisms prior to the project, incorporating subsidies, broadening the project to include agricultural and water issues (integrated design), improving conditionality and competition in subsidisation, incorporating capacity-building measures, exploring farmers' organisation options (community-based), building partnerships and coalitions with mediating stakeholders (environmental stakeholders, banks), and promoting success stories. These improvements do not represent an exhaustive list and should be further discussed and complemented with stakeholders to provide an optimal re-design.

2.13 Why is the project design important?

The project design is a key part of the cycle for optimal conception and implementation of SEF projects. (See Part 9.) This cycle is recommended for designing and reforming SEF projects with involved stakeholders and building capacities at different phases of the project's conception and implementation. The project design represents a key part of the project conception, and must be preceded by participatory processes of defining the objective functions and analysing the project's case. The project-design process should consider different technical and institutional/policy options (Parts 7.1 and 7.2) and weight them according to the reality of the case study and the objective function. In the SEF Azraq case for example, there was an overemphasis on technical options with no detailed analysis of institutional options, and little consideration of farmers' and the basin's realities. Such issues that determine the level of participation and feasibility should be considered as a part of the project design. Furthermore, the project's design was restrictive in the sense that it did not allow produced energy to be used for farming activities as practiced in international cases which, for example, combine solar energy sale with on-farm use in improved irrigation systems. International experiences provide valuable insights and options that can widen the used perspective of SEF in Jordan and in other cases and provide a basis for more detailed deliberation on future projects.

3

CONTEXTUALISING SOLAR ENERGY FARMING

3. CONTEXTUALISING SOLAR ENERGY FARMING

3.1 Use of the term of solar energy farming (SEF)

Solar energy farming (SEF) is not a precise term, as the described activity (solar farming) can be found in relation to various ownerships, and land and sea use types, and also for different purposes. In practical terms, SEF is used to describe ideas under an application of any of the following categories:

SEF as a stand-alone system

SEF, or solar farms, can refer to large utility-scale installations of photovoltaic (PV) systems to generate clean electricity. In this case, no combination with agricultural production is envisioned. Landowners are usually receiving rent for land which otherwise could have an agricultural use value. Solar farms are found in many places in US states such as California, North Carolina, Nevada, etc., or in Europe, China, and India among other places. SEF can also imply smaller plants dedicated mainly to solar energy production with no agricultural use. In the US, some farmers, e.g. in North Carolina[1] and California[2], are converting their land from traditional farming to solar farming in the pursuit of a higher and more stable income.

SEF as a combined system

SEF as dual systems.

SEF can refer to hybrid systems of agricultural land use and solar energy production on the same land unit. There are many combinations for land use with solar installations with the aim of conserving biodiversity, protecting land from erosion, or providing grazing for livestock. (See Hernandez et al. (2014) for technologies, and BRE (2014) for best practices from the UK). In Germany for example, around 11% of renewable energy capacity (mainly solar and wind) in 2012 was owned by farmers, and, at the same time, some marginal land (e.g. old airfield sites) was used for solar power generation combined with grazing activities (IRENA, 2015a). One idea within these systems is to produce solar energy and crops from the same piece of land by changing the configuration of solar panels to allow for crop production underneath them. This idea is promoted for certain crops and regions as a way of providing additional security against droughts and income loss (e.g. Goetzberger & Zastrow, 1982; Kuemmel et al., 1998). Today, this technology is being used and further refined. In Japan for example, where 10% of farmland is unused, the government has developed incentives so that solar farms are only economically viable if combined with agriculture, e.g. by planting potatoes or mushrooms underneath the solar panels[3].

SEF as agricultural modernisation.

The term SEF can be used in reference to efforts to modernise agricultural systems in order to incorporate renewable energies. This includes vast governmental programmes supporting farmers in deploying solar pumps or SPISs. The production or selling of excess solar power can be a secondary objective. Here, the impact of solar energy use in agriculture is mixed and site-specific. On the one hand, the use of solar energy can help to improve on-farm energy use efficiency for water pumping and distribution, or for other purposes such as heating, drying, and grinding. On the other hand, the availability of solar *energy can lead to higher water use abstractions. For example, solar pumps for groundwater abstraction and irrigation can lead to cost saving for farmers, and in some cases can indirectly cause an increase in water use.*

This report aims to compare and assess solar farming to draw lessons applicable to the solar farming project in the Azraq basin in Jordan. Because of this, only some specific applications under SEF will be used as examples. For this practical reason, the term SEF in this report is used to describe agricultural–solar (sometimes called agri-voltaic) utilisation systems where used arable land is either enhanced with, or converted to, solar energy farming. In this sense, the focus of the report is on investigating the link between agriculture or farmers and solar energy, but with the aim of highlighting experiences and options for farmers to use solar farming as a source of livelihood. In this sense, stand-alone, often commercial farms (commonly known as solar farms) on non-agricultural land or unused arable land are not the focus here.

Under the SEF term definition used in this report, there is another differentiation to make within the plethora of approaches in combining voltaic and arable land use:

Solar energy farming with a Power Purchase Agreement.
Solar power can be deployed on used arable land (farms) for many different reasons (irrigation, water pumping, chilling, distribution, *etc.*). In the event of availability of a PPA, some of these activities can change or decrease. In some cases, farmers can convert their farms and become solar entrepreneurs, giving up agricultural livelihoods and selling all of their produced solar power. In fact, this is the intention of the solar energy farming project in the Azraq basin in Jordan (SEF Azraq), namely substituting traditional farming with solar farming in order to decrease groundwater abstractions. Analysing those SEF applications that have a PPA constitutes the key theme in this report.

Solar energy farming without a Power Purchase Agreement.
In the absence of a PPA, SEF is commonly used for agricultural modernisation as, for example, SPISs, solar pumps and/or other applications not related to agricultural water. These applications are quite common and are not the focus of this report. They are, however, included in the analysis (the case of India and some Arab countries) as they represent important precedents to projects on SEF with a PPA. In fact, a PPA can be introduced to any on-farm solar application, offering farmers the opportunity to replace or supplement traditional farming with solar farming. In this case, the introduction of PPA to agriculture-oriented SEF applications make these applications conceptually and practically very close to the examined case of SEF Azraq.

In conceptual terms, SEF is an exemplary topic combining the three sectors in the water–energy–food security nexus (WEF nexus). It thus needs to be framed in relation to resource potentials, trade-offs and synergies caused by the SEF technologies and the objectives of SEF interventions in a specific context. Figure 1 shows four different hypothetical set-ups of the SEF decision-making dilemma in two different contexts representing resource potentials and current uses. In an "arid environment", one would expect the solar energy potential, and thus the optimal resource use threshold, to be higher than that of land and water. Under Scenario A, water and land are constrained by natural scarcity but are overused beyond the optimal threshold. In contrast, the solar energy potential is still largely unexploited. This is typical of many Arab countries, including Jordan. Scenario B represents a larger (than A) and unexploited potential for water and land use with a large but underdeveloped potential for solar energy. This could represent countries relatively abundant in water and arable land with an arid environment, *e.g.* Sudan. In "wet" environments, water and land potentials can be relatively higher than solar energy potentials. Under Scenario C, the full agricultural potential is largely exploited, to the detriment of water (*e.g.* some EU countries such as Spain and France, parts of the USA, and Australia). Scenario D represents underdeveloped agricultural and water-use potentials with a lower potential for solar energy (*e.g.* Japan, Brazil, *etc.*).

Depending on the context of potentials and current uses, the policymaking objectives with regard to SEF can differ. In general, the limiting factor and the prime objective in the WEF nexus of SEF is water. At the same time, the goal of increasing solar energy is a positive common denominator in all scenarios. The feasibility and desirability of increasing agricultural land use will depend on water availability. Thus, bearing in mind that increasing the share of renewables is a common, non-restrictive goal, two major strategies underlie the different scenarios and determine the SEF approach:

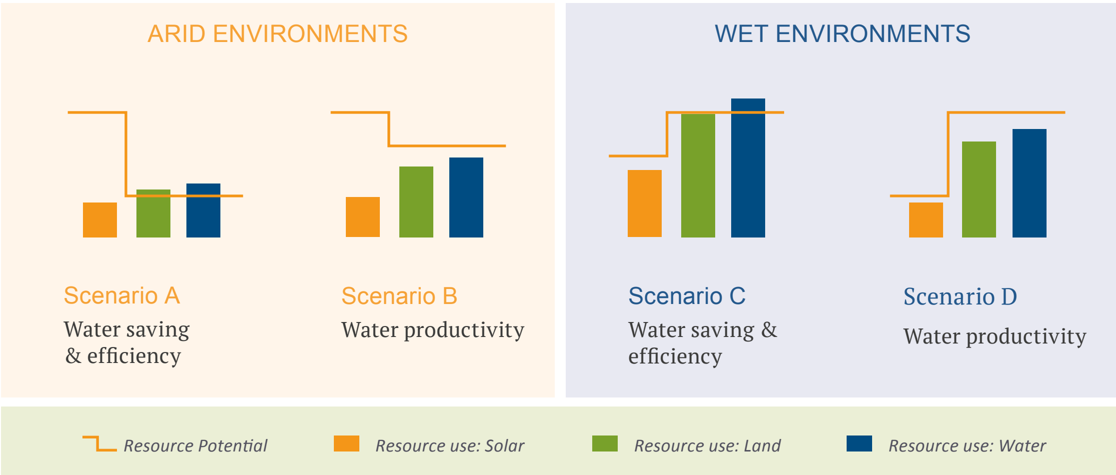


Fig. 1: SEF objectives under scenarios of resource potential and use patterns

3.2 Solar energy farming as a nexus and development innovation

The trend of increased energy–land integration is on the rise in developed as well as developing countries. There are multiple reasons for this increased integration, while the reasons for this growth of applications such as SEF can be summarised into three interlinked categories: a) the overall rise of renewable energies and their emerging use potential for agriculture; b) comparative advantages of renewables such as solar energy in agriculture; and c) public policies to improve water, energy or/and food securities through SEF. These three categories of drivers are specific to the rise of SEF, which are themselves caused by larger societal challenges such as climate change impacts and the need to increase clean energy and reduce emissions, as well as the rapid population and economic growth which cause additional demands for food, water, and energy. These societal "grand challenges" have led to the rise of renewables use in agriculture (Category 1 of SEF drivers), but internal drivers of cost-benefit of technology (Category 2) and public policies (Category 3) have proven to be accelerating and largely independent factors behind the rise of SEF.

Firstly, environmentally friendly renewable energies (wind, solar, geothermal, biomass, hydropower, *etc.*) have grown significantly in recent years and are replacing or augmenting the current energy sources. In light of global agreements such as the 2015 Paris Agreement along with the need to decarbonise economies and reduce global CO2 emissions, one can expect significant growth in the use of renewables. They will power key economic sectors in developing countries. Indeed, in India for example, the renewable electricity capacity will double by 2022. Already now, solar PV and wind energy represent 90% of capacity growth due to decreased costs in India, while in other countries, renewables are showing record-breaking growth each year in both the northern and southern hemispheres (IEA, 2017). In Jordan for example, according to the National Energy Strategy Plan, renewable energy is anticipated by 2020 to reach 10% of the total energy supply mix. The water sector is one of the major energy consumers, with 15% of total energy demands in the country being used for water pumping[4]. The sector is therefore targeted for renewables use and increasing energy efficiency (Ministry of Water and Irrigation, 2016a). Sectors such as agriculture and water are going to benefit from renewables. Farmers are witnessing the changing reality concerning electricity sources and analysing the potential effect on their livelihoods. In fact, renewable energies can replace current energy sources and make relatively cheap energy available for various uses in agriculture. Renewables can be used for various purposes in agriculture such as water heating, water abstraction, crop drying, grinding of grains, greenhouse heating, lighting of facilities, *etc.* (see Chel & Kaushik (2011) for an overview).

Secondly, the favourable economics of renewables such as solar energy will allow for an increased, bottom-up adoption by farmers in the future. In particular, if fossil fuel subsidies are not present, farmers recognise the comparative advantages over fossil fuels in the long term (*e.g.* when the fixed costs are distributed over 10 or 20 years). The advantages of solar energy use are plenty in terms of the low running or variable costs, the modular nature, the relative reliability or endurance, and the avoidance of emissions, pollution or soil contamination by the fossil fuel liquids. Two important factors are expected to increase the adoption of solar farming in agriculture. The first factor, a favourable one, is the fall of the module prices of PV systems. For example, in the United States alone, the price decrease is expected to accelerate by as much as 75% in 2020 in comparison to 2010 (Goodrich et al., 2012). Globally, in the last 30 years, the cost of PV declined by almost one fifth each time the cumulative installed capacity increased twofold (Cengiz & Mamis, 2015). The second factor is the out-phasing of energy subsidies for fossil fuels, thus accelerating the use of renewable energies even further. The Middle East and North African (MENA) region harbours almost half of the global pre-tax energy subsidies, and many MENA countries have started to reduce the market-distorting subsidies (Verme & Araar, 2017; Meltzer et al., 2014; Al Iriani & Trabelsi, 2013). Especially since the fiscal crises caused by falling oil and gas prices in 2014, many countries in the region have been eager to phase out such subsidies. In the agricultural sectors, the use of subsidised fossil fuels is prevalent. The decrease of PV costs, the increase of fossil-fuel prices, and the provision of incentives for renewables (*e.g.* feed-in tariffs, tax breaks, and subsidies) are expected to increase the rate of return for options such as SEF. It should be noted that

BOX 1: WATER USAGE IN SOLAR APPLICATIONS ON FARMLAND

The implications of SEF applications on water usage is difficult to analyze without some basic differentiations based on comparisons to a baseline scenario. First, the question is SEF has some advantages with regard to water use over energy sources. If one examines the water requirements over a lifecycle of different renewable and non-renewable energy resources, solar applications offer important comparative advantages. IRENA (2015a) provides an overview of water requirements of different energy production systems (renewables and fossil) based on a full life cycle approach (extraction, processing, transformation *etc.*) and on an energy-system level. Solar and wind energy are among the most water-efficient production systems from a "litres per MWh" perspective and with regard to expected water saving if water withdrawals and consumption of the water-intensive fossil fuels were to be replaced with solar or wind energy. In this sense, SEF as a part of push to increase renewables use will help save water, especially in Arab countries, which largely rely on power generation from oil and gas. Secondly, one can pose the question of whether the dissemination of SEF can increase on-farm water usage. Here, this question cannot be answered without looking at the specific SEF application and the institutional context. In any SEF application, the maintenance of the solar panels requires regular dust cleaning using water which could vary significantly in different environments from once in two weeks to daily (see Mani and Pillai, 2010). In Jodhpur, India, some PV panels are cleaned four times a month during summer season and twice during winter, each time consuming 20,000 litres for each 0.5 MW block (Santra et al., 2017). However, there are more efficient cleaning systems that better suit arid Arab countries that require very little or no water input (He et al., 2011). Overall, the water requirements for cleaning should be analysed in the specific environment and compared to the potential impact of SEF on irrigation water use, in cases where SEF is combined with SPISs or solar pumps. The impact of SPISs on water use efficiency is a controversial topic and, as for other irrigation practices, largely depended on the technology deployed and institutional arrangements in place. On the one hand, SPIS have zero operational costs and therefore do not encourage water conservation (Kishore et al., 2014). On the other hand, the operation of SPIS is restricted to sunshine periods while these systems usually pump less dynamic heads than diesel or grid systems. For these reasons, one would expect water abstractions to be lower than with diesel pumps for example. However, as the case of SPISs in India shows, high state subsidies and inadequate farmers' capacities can result in overexploitation of groundwater resources as a consequence of the dissemination of oversized (larger capacities that needed) systems and increased access to solar energy in agriculture (Shah et al, 2016, Shim, 2017). In order to alleviate these problems, recent projects have evolved to combine the provision of solar technology with efficient irrigation technologies and conditions for irrigation scheduling and conservation. Furthermore, SEF with PPAs is increasing and can be designed in various ways in order to improve participation incentives, financing, enforcement and water use reductions. (See Chapter 7.)

land prices represent an important cost factor for PV systems. This means that solar energy investors need to rent and buy land, something that represents an important component of the initial investments. For farmers using their own land to produce solar energy, this cost factor might be less of an issue. This is especially true for large farmers who can use a portion of their farms for solar power production for sale or on-site use. In this case, it is important to note that the economics and financial benefits is site-specific and will depend on the specific SEF application. SEF as a stand-alone system, (*i.e.* for power sale only), can be more profitable than traditional farming if the FIT is high enough. In addition, the SEF as combined systems (*e.g.* with irrigation, pumping, and dual uses) can lead to a higher rate of return than using only fully-priced fossil fuels in traditional farming, and might increase if an attractive PPA were offered. For example, according to KMPG (2014), current economics show an internal rate of return for replacing diesel pumps with solar pumps of around 10% to 19%, depending on whether additional benefits such as increased crop yields are achieved.

Thirdly, and more related to the projects analysed in this report, public programmes and donor funds are steering the transition towards renewables use in agriculture. The motivation behind this push depends on the developmental context of a specific country or region. In developed countries, the primary reason lies in the reduction of the carbon footprint by achieving renewable energy targets. Here, SEF applications are oriented towards encouraging renewables deployment in agriculture, but also towards the co-location of renewables with agriculture.

Here, the debates on solar energy applications on arable land focus on minimising the trade-offs between energy production and the loss of land productivity. In order to do this, one can reduce the area of the land required for large-scale renewable energy projects, while allowing and financially supporting land use for grazing, livestock, and selected crops (dual systems). This land–climate–energy nexus is a key priority in developed countries (see Dale et al., 2011). In developing countries, the focus might be more on the water–energy–food–livelihood nexus. Promoting the wide range of SEF applications is in a broader sense associated with different specific aims, as for example improving resilience of farmers to price and market volatilities, empowering farmers, improving yield, providing additional income and, potentially, helping to save vulnerable water resources. At the same time, the reason behind any individual SEF project is specific to the local development and environmental context. For example, newer SEF programmes and projects in India and Jordan share a common objective of improving livelihoods and farmers' income, and offering the sale of solar power as an alternative income. In the case of SEF Azraq, the idea is to encourage farmers to give up some farming activities in exchange for solar farming, thus leading to reduced groundwater abstractions in these water-scarce regions. In the Indian case, substitution of livelihoods is targeted through SEF applications as combined systems (linked to irrigation, pumping, and on-farm use), with a PPA as an option for farmers to reduce on-farm solar energy use, and thus ultimately reduce water use. As this report will discuss later, there are many technological and socioeconomic options that can be explored in the set-up of SEF with a PPA.

3.3 Insights from international experiences

The push for renewables use has prompted different applications of SEF under different objectives. SEF is thus a broad term encompassing innovative international projects linking solar energy to land use in general, and in particular to improving water and food securities as well as the access to energy. Literature on the renewables in the WEF nexus reveals many innovative ideas for achieving increased integration through solar energy use. These innovative ideas cover a range of dual systems in solar farming and sharing. (See IRENA, 2015a.) More recent innovations include the splitting of solar spectrum (solar unbundling), allowing for an optimal sharing for different WEF uses (Gençer et al., 2017). Many such new applications are yet to be transformed into projects. Table 1 provides key insights from some real-world applications using different applications grouped under the term "solar energy farming".

International experiences of SEF show the variety of applications and variables determining the SEF outcomes. Some insights into the critical factors that affect the feasibility and cost–benefit relationship of SEF projects can be briefly mentioned here:

Water conditions and input land.

The availability or scarcity of water resources determines land-use potential and any necessary measures to restore, save or increase the productivity of the resource. Groundwater conservation plans, water harvesting, improved monitoring, and cropping changes can all be linked to SEF. The availability of a reliable supply of electricity at very low marginal cost on a farm level can exacerbate water depletion though increased abstractions. Furthermore, other sensible issues for SEF success are related to land as input. If land is exclusively used for SEF, the alternative use of land influences the rate of return. Besides, in the financial cost–benefit analysis of farmers, land has non-use values related to cultural identity, landscaping and other factors.

Technology choice.

The technological set-up of SEF is key in influencing the trade-offs within SEF. For example, the size of the installation affects the profitability. Dual systems allow for sharing the same resource. In addition, solar energy can be harvested for different uses whether through electricity or heat. Solar installations themselves require water for cleaning, especially in conditions with frequent sand storms and dusty winds. The battery requirements depend on radiation and the desired storage capacity, and besides, the costs of solar installations such as pumps in deep groundwater aquifers often need to be subsidised for small-scale farmers.

Farmers.

The socioeconomic characteristics of farmers require careful consideration. For example, in countries where access to energy and machinery is available, small-scale farmers might have small land plots and high cropping and irrigation intensities. The marginal cost of land is thus high, while non-use values can be considerable. Although small-scale farmers can be highly interested in the additional income from SEF, they often cannot afford the high fixed costs, nor do they have enough land to provide economies of scale. In view of this, the conditions of these farmers and their willingness to reorganise in cooperatives or community-based management schemes needs to be studied in *advance. In contrast, large-scale farmers might adopt renewables by themselves if they recognise the potential profitability. Due to the usually higher productivity of land, their opportunity costs for replacing farming with large-scale solar installations is high. This is especially true if they are profiting from the use of underpriced water. Furthermore, wealthy, large farmers might be less interested in reorienting their activities towards new sectors such as renewable energies. This is the case if the new profession is involved with uncalculated competition and policy risks as well as transaction costs. For example, significant investments are needed for developing new capacities, while the energy price is not stable. Moreover, in developing countries, elites who do not earn much of their income from farming might still own large farms, and thus are not concerned about profitability. However, large farmers can still be a driving force of SEF. This is the case in well-run farms whose management is open for solar modernisation and the adoption of dual systems of SEF in the pursuit of profitability.*

Institutional environment.

The institutional arrangements determine crucial parameters such as pricing policies for water and conventional energy, incentives for renewable energy use, regulations and their enforcement, and the role of public companies. Firstly, heavy subsidisation of water, electricity and diesel make conservation less of a priority for many farmers in developing countries, and thus the savings from solar power use become negligible. Even in the case of availability of adequate pricing schemes, enforcement and monitoring are necessary. In conditions of extreme scarcity, universal metering is advised. Furthermore, SEF can be a profitable option for farmers only in the case of adequate feed-in tariffs and suitable grids. Public engagement in SEF can be crucial in providing loans or subsidies for small-scale farmers. The access to capital and financing mechanisms such as public subsidies is instrumental for the promotion of SEF in countries such as India, whether with regard to SEF applications without a PPA or newer ones with a PPA. (See Chapter 6.) In Jordan, alongside the disagreement on the PPA, the ambiguity about the access to finance and credit is a major obstacle for the implementation of the SEF project. Furthermore, there are also multiple options for a stronger public engagement to achieve certain societal objectives of SEF such as curbing excessive water use. For example, public–private partnerships (PPPs) or incentives for private companies can offer comparatively cheap solar power for farmers by using large-scale solar farms. In exchange, water and energy use is monitored and regulated. Here, farmers install meters and pay for the billed use of solar power for water abstraction. In addition, the government can be engaged in capacity building and on-farm support for small-scale farmers seeking to install SEF. In exchange, farmers must adopt conservation practices and allow increased monitoring. In fact, the basic technical, as well as managerial, capacities of famers to engage in SEF can be important reasons for their unwillingness to change their current land-use patterns. Knowledge promotion along with assurances through institutional arrangements can support farmers in adopting renewables-based approaches such as SEF applications. On the wider scale, the promotion of integrated land and renewables management as a serious livelihood option for traditional farmers in the 21st century needs a strong public engagement and awareness, and the trust of farmer communities.

Country/ region	Main motivation/objective	Deployed technology	Challenges	Some solutions
Solar energy farming with a power purchase agreement				
India	Mainly improving farmers' livelihoods	High subsidisation of solar pumping systems; new projects offer a FIT tariff based on net-metering	Increased groundwater abstractions	Linking solar farming subsidies to water harvesting and efficient irrigation; experimentation with remote monitoring; purchase guarantees for surplus solar power in order to substitute agricultural use
Japan	To increase agricultural output and food security	Dual systems that allow for sharing the same plot for solar energy and food production	Convincing famers to use land whi-le producing solar energy	Financial incentives that make solar power in combination with agricultural production attractive; technical design for joint optimisation of solar panels and farms using concepts of solar sharing
USA (*e.g.* California and North Carolina)	Farmers are faced with increasing energy costs and decreasing profit margins	Modernisation of farm-level electricity generation through solar energy; selling of solar energy surplus	Fluctuation of solar energy prices	Modernisation of energy systems (*e.g.* storage components) and increasing energy-use efficiency on-farm level
Canada (*e.g.* Ontario)	A public effort to increase use of renewables by farmers and households	Solar micro-generation plants (10 kW and below) are promoted through state programmes with good purchase tariffs	Conflictive use of land between agri-culture, solar energy production and biofuels; decrease of agricultural land	Use of SEF on marginal lands; joint use of land for SEF and livestock or wild pasture
Solar energy farming with a power purchase agreement				
Egypt	Increasing agricultural productivity of desert land	Promotion of solar energy pumping systems	Negative impacts on water use	Initiatives to link solar pumping to efficient irrigation schemes
Morocco	Improving agricultural livelihoods and water-use efficiency	Subsidisation of solar pumping systems on the condition that farmers buy micro-irrigation technologies	Water use might not decrease; irrigati-on might expand; no effective control	Aquifer contracts should establish clear plans for groundwater protection and restoration on a voluntary basis.
Pilot projects not yet implemented				
Jordan	Substitution of agricultural activities through solar power production and sale of power	Piloting an SEF plant by farmers on their agricultural land	Ensuring acceptability, stakeholder participation, and low-cost financing; no power	Different design options and institutional arrangements being discussed, including extending power purchase agreements to the agricultural sector

Table 1: Some selected examples of SEF projects

4

NEXUS ASSESSMENT

4. NEXUS ASSESSMENT

4.1 Overall nexus relevance

SEF applications using solar energy on a farm level can be analysed for their contribution to minimising WEF nexus trade-offs or maximising synergies between the sectors. There are many possible ways to set up an SEF project. The actual potentials and patterns of water, energy and land use, the realities of farmers, and the institutional–technical design of the SEF scheme determine the shape of trade-offs and synergies. With regard to SEF schemes, the SEF core trade-offs and synergies between water, energy and food securities can be mentioned briefly here:

Trade-offs.

Solar farms require land and water for cleaning and cooling – if not constructed as floating systems as, for example, in the case in Huainan in China[5], or in London, UK[6]. If productive land is required and scarce water is used, a trade-off arises between energy security on the one hand, and water and food securities on the other. In addition, SEF conceived as solar modernisation of farms without PPA can lead to the over-abstraction of water. For example, in a cross-regional comparison, solar water pumps were found to have a short payback period of around 4–6 years with huge savings over longer periods (Chandel et al., 2015). There is an evident cost argument for solar energy in farming, and besides, many governments give subsidies for the purchase of solar pumps. Farmers can thus have year-round, uninterrupted access to daytime energy at low cost for low-pressure pumping or other agricultural activities. If there are no conditions for responsible water-use practices, overuse of water can be the result. In order to minimise such trade-offs, there should be better incentives to save energy and water. A PPA provides the valuable ability of grid connection and the selling of the excess of produced energy at a subsidised price. It creates an opportunity cost of inefficient or wasteful use of solar energy. Alternatively, energy surplus can be directed towards other productive on-farm uses (e.g. heating, chilling, grinding, etc. However, this approach might be difficult economically in the context of large numbers of scattered wells and farmers and might only be feasible on the level of mini-grids for villages or small communities. Furthermore, subsidies for solar installations can be set lower in water-vulnerable regions in order to encourage economisation. High subsidies can lead to farmers buying oversized SPISs, and thus increasing water use. Reforming subsidisation needs to come along with improved capacity-building of farmers on key topics such as maintenance, cropping management and sustainable agricultural practices. In addition, smart and integrated subsidy policies for solar energy technologies help to reduce risks. In Morocco for example, subsidised solar equipment can only be acquired if farmers purchase micro-irrigation systems for efficient use of water (Kingdom of Morocco, 2014). A similar approach is proposed for the case of India (See Shah et al., 2014; Bassi, 2016). Finally, in order to minimise the trade-off with land use, responsible land-use practices can be attached. For example, grazing and landscape plans can be established in order to harmonise land and energy aspects.

Synergies.

In cases where water is scarce and vulnerable to overuse by agriculture, reducing farming activities or increasing water-use efficiency is needed. Here, SEF as stand-alone or in combined systems with a PPA can lead to water-use reductions if adequate controls are in place. For example, SEF Azraq seeks to substitute farming with solar farming, thus reducing water abstraction by reducing farming activities while increasing, in a modest way, renewable energy use in Jordan. Such an approach is straightforward, and results in synergies with no obvious trade-offs – noting that the loss of agriculture is assumed to be a positive effect. SEF as combined systems with a PPA (e.g. India) can lead to similar synergies if the produced solar energy is sold instead of using it for pumping or irrigation. Furthermore, other synergies can arise in contexts where water availability is not an issue. In this case, SEF can increase food and energy securities through the aforementioned dual or hybrid systems. Such systems promote land and radiation sharing for energy and crop production. Solar energy-powered greenhouses are a similar approach to maximising the use of renewables and land, for example in China[7]. Solar greenhouses and solar-based aquaculture can be especially valuable in cold or temperate environments where they can serve for winter food production, while excess energy can be sold (see Mussard, 2017). In fact, solar energy can be used in many different areas to enhance agriculture while improving access to energy. For example, in China, photovoltaic energy is being used for agricultural greenhouses, in fisheries for breeding installations, for wastewater purification, in water pumping, and for improving rural electrification (Xue, 2017). In general, alongside water abstraction and irrigation, there other productive uses of solar energy on farms that cannot be explored in the limited scope of this report; e.g. heating, chilling, drying, grinding, distribution, etc. (see Chel & Kaushik, 2011).

The highlighted trade-offs and synergies arise from core functions of SEF projects that can interfere with current uses and potentials of water and land resources, and any societal goals to conserve them or reduce their use. Figure 2 shows examples of the expected gains and losses of SEF in light of actual resource potentials and uses for some case studies. This is based on specific SEF applications used in the country, and the current debates about the net gains or losses from the current form of SEF institutional and technological design.

In addition to the core goals of a SEF project, a more integrated project would incorporate other ideas that can minimise trade-offs and create more synergies. These “add-ons” in a fictional “integrated” or “smart” SEF project are mentioned here in the categories of water, energy, and food securities:

Water security.

A SEF installation can be coupled with measures to protect water resources and reduce water use. For example, SEF can be embedded within larger groundwater management strategies. Groundwater management plans are cross-sectoral, often negotiated, strategies that stipulate a wide range of future measures. SEF can be a part of such plans, be linked to existing ones, or be conditioned on the development of such strategies. There are other forms also. In Morocco (Souss Aquifer) and France, aquifer contracts are signed among concerned stakeholders to outline and operationalise restoration and protection measures. (See Closas & Villholth, 2016.)

At the farm level, SEF needs to enhance capacities to monitor water use, e.g. using cellular phones connected to the SEF installation. Metering and farm-level water-use efficiency plans can be developed for SEF projects. In addition, SEF can incorporate measures to improve water availability, e.g. through the development of rainwater harvesting practices or by linking SEF to aquifer recharge plans. Using SEF in combination with rainwater harvesting can be a promising option, and its applicability for cases such as Jordan be explored in more detailed analyses. Here again, current experiences show the need to link SEF to other issues such as irrigation and water use in general. The highlighted experiences from India in the States of Rajasthan and Odisha (Chapter 6) include projects that link SEF to the construction of recharge shafts where water can be pumped for irrigating certain water-efficient crops and be used for recharging groundwater. Vulnerable communities can be involved in these efforts, which can benefit from increased access to energy.

Food security.

SEF needs to consider the food production and food security dynamics. In order to do this, SEF projects need to establish links to extension services, Water User Associations (WUAs), or similar institutions for improving farmers' capacities and representation. As a result, programmes or measures for increasing water productivity and use efficiency (e.g. changes in cropping patterns or timings, and farmers' education on sustainable irrigation practices) can be linked to the activities of SEF projects.

Energy security.

The agricultural and food sector can be an important electricity consumer, accounting for approximately 30% of global energy consumption and, as an example for national level, 22% of total electricity consumption in India[8]. This value is sometimes higher at local or regional levels. In other cases, the agricultural sector is in small demand and harbours small-scale, unproductive and scattered solar farms. In such a case, off-grid SEF solutions might be more suitable, as the costs of connecting these farms or many small mini- or micro-grids to the network are high. Here, it is vitally important that SEF considers electrification plans and energy conditions at local, regional, and national level, as this offers possibilities to rethink the optimal design of SEF. For example, instead of feeding it into the grid, the solar energy can be utilised locally for productive use and added value on site, desalination, or wastewater treatment, thus providing alternative water sources to be sold to other farmers or used for recharging aquifers. In this way, farmers help indirectly through their solar farms in saving the resource base of their agricultural livelihoods.

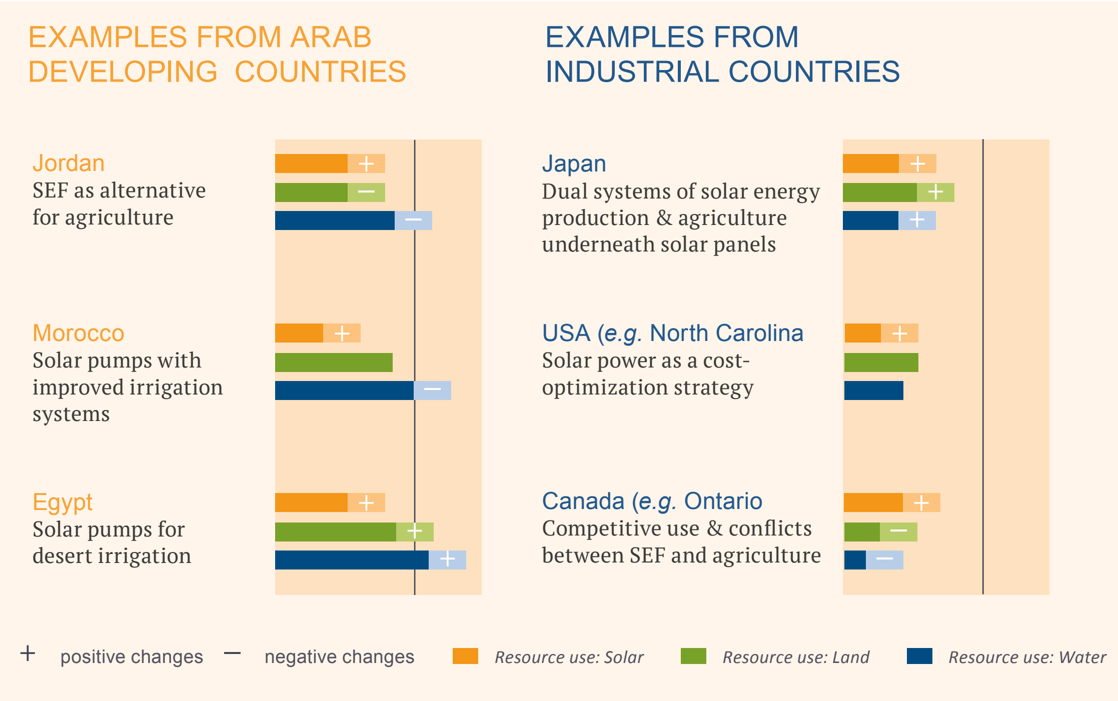


Figure 2: Case study examples of possible resource use changes as a result of SEF projects

4.2 Relevance to the Arab context

Innovations to improve resource-use efficiencies and achieve better integration, as promoted by the WEF nexus idea, are highly relevant for the priorities of Arab countries. The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) highlighted in a series of policy briefs the importance of the WEF nexus for Arab countries' development priorities (GIZ, 2016). In particular, the WEF nexus approach is instrumental in mitigating risks and providing opportunities for increased resource-use efficiencies and enhanced institutions and capacities. SEF is capable of contributing to many of these aspects; for example, the use of renewables in agriculture will help to decrease the use of fossil fuels while improving the resilience of farmers, who will become less dependent on fossil fuels or electricity grids. In this way, SEF can help to mitigate climate risks by reducing emissions and risks related to volatility of fossil-fuel prices. Furthermore, it can help reduce government spending on energy subsidies, which are very high in the region: *e.g.* around 14% of GDP in Iraq, and 10% in Egypt and Saudi Arabia (ibid.). In the event that excess energy can be fed back to the grid, this contributes to national targets for renewables, and to achieving energy security at large. Renewable and solar energy use will help to increase electricity access in many rural and poor parts in the Arab region. As a result, the use of renewables in food production has been embedded in renewable energy strategies in different countries of the region. SEF applications represent a part of this push to increase renewables in agriculture. One example is the use of solar pumps, which this report defines as a combined SEF system. In Tunisia, the 2008 Renewable Energy Plan in Tunisia aimed at promoting renewable energy applications for the agricultural sector, and rural electrification. It envisioned the installation of 63 wells with PV pumping stations and desalination units, 200 water-pumping stations for irrigation, and the promotion of biogas use for the production of heat and power either consumed on-farm or fed into the grid (Bryden, 2017). Besides, some countries in the region, such as

Morocco, Jordan and Egypt, have already established laws with feed-in tariffs that open the door for profitability of renewable energy applications.

Another major contribution of SEF is with regard to potential benefits in addressing the regional challenge of water scarcity. Most Arab countries are either in the category of extreme water scarcity, or will be there soon (see UNDP, 2013). Often, hydrological infrastructure and rainwater harvesting are limited and water reuse is not exploited, and thus limited groundwater resources are overused. This is the case, for example, in countries of the Gulf Council Cooperation (GCC), Jordan and Yemen. The latter has around 8,000 private drill wells with effectively no monitoring or enforcement (UNDP, 2011). In some cases, solar farming can be designed (net-metering of SPISs or pumps) to provide an alternative livelihood for small-scale farmers, thus helping to control over-abstractions. SEF can also be oriented towards off-grid solutions through modernisation of on-farm facilities, *e.g.* solar pumping, heating, distribution, *etc.* In addition, SEF projects can be linked to improved irrigation efficiencies, and thus help to reduce water use. This is the case in some projects in Morocco and Egypt, for example. Here, the GIZ implemented a project entitled “RaSeed – Green Energy in Agriculture”, which developed a network of partners that explores solar pumping technologies in combination with water-efficient irrigation systems suitable for new, desert lands[9]. The focus here is the efficient use of groundwater. However, the project did not target achieving a PPA. It is therefore not related to the core focus promoted and analysed by this report on SEF applications with a PPA.

4.3 Relevance to the Jordanian context

SEF in the context of Jordan has been studied and shown to be beneficial on several fronts. The main justifications and supporting arguments can be summarised briefly here, largely based on GIZ & Lahham (2017), Prinz (2016), GIZ (2016), and Daradkah (2014).

Saving fossil fuel subsidies

- More than 95% of energy in Jordan is imported.
- Energy subsidies accounted for 2.8% of GDP and around 9% of government spending in 2012 (Atamanov et al., 2015).
- Energy generation using fossil fuels emits more than 17 million Mt of carbon dioxide annually.
- The energy cost of the water sector is expected to increase by 50% in 2017–2025, leading to additional energy-subsidy expenditures.
- SEF contributes to reducing fossil fuels and reducing the government budget deficit.

Contributing to the increase of renewables and improving energy efficiency

- 14% of the country’s energy demand is produced by water delivery (Ministry of Water and Irrigation, 2016b).
- Electricity demand is increasing, predicted at an average annual rate of about 6% (Jaber et al., 2001).

- The influx of refugees increases energy demands.
- Renewable energies are scheduled to increase to 10% of total power supply by 2020. This target is also 10% for the water subsector by 2025 (Ministry of Water and Irrigation, 2016a).
- If the agricultural sector uses SEF, it contributes to the increase in renewables
- SEF can help to improve energy-use efficiency due to improved technology and better monitoring.

Conserving groundwater resources and wetlands

- Jordan is one of the countries with the highest water scarcity in the world, with a per capita water availability of less than 150 cubic metres per year, in comparison to 9,000 in the US[10].
- Currently, the annual water deficit stands at 550 million cubic metres. This deficit is expected to continue in the future, reaching 26% in 2025, or hopefully 6% with the opening of the Red Sea–Dead Sea Project (Ministry of Irrigation, 2016b).
- Groundwater contributes to about 61% of total water supply, with 160 million cubic metres out of the total 972 million for water supply supplied by over-pumping from groundwater resources (ibid.).
- Six out of the 12 major groundwater basins are over-extracted (ibid.).
- If farmers use less groundwater due to better profitability of SEF, this can save valuable water.
- As some see water reductions to be a main contribution of SEF projects with PPA, the conceivable benefits from reduced water abstractions resulting from successful SEF projects are plenty: rehabilitation of aquifers and ecosystems, recovery of biodiversity, land restoration, safeguarding economic resources etc. Other benefits mentioned in this subchapter (*e.g.* saving subsidies, climate change contribution, fulfillment of water strategies) link to this argument.
- SEF projects can be implemented as co-production systems of solar energy and agriculture or merely as agricultural modernisation (*e.g.* solar irrigation). In such a case, some groundwater amounts can be saved in Jordan, if irrigation practices are improved or total agricultural land decreases as a result. However, the realization of such benefits depends on the individual project design and case context (see previous chapters).
- In the best case, farmers abandon year-round irrigation of annual crops in exchange for a better income through SEF. An SEF unit on 1,000 square metres of farm space can save 1,000 cubic metres, the annual consumption of around 1,000 people (Prinz, 2016).
- Agriculture consumes around 65–75% of water resources, although Jordan is a net importer of 98% of consumables (including more than 95% of cereals and 100% of rice and sugar[11]). Exported products such as olive oil are vulnerable to increased soil degradation, groundwater losses, and climate change.

Improving farmers' livelihoods

- Around 25% of the poor population depend in some form or another on agriculture.
- According to the technical feasibility study, depending on the financing of SEF projects, a farmer can earn at least four times the annual income from agriculture (around €250 per dunum - 1,000 square metres- per year) if he or she dedicates his or her farm land to selling solar power. This assumption is made using a feed-in tariff of €0.13 per kWh, a 5% interest rate, and no subsidies for the fixed costs (Renac, 2012). However, such calculation might change with changing food market dynamics, making the financial viability of SEF projects variable to changing crop prices.
- Although not a part of SEF Azraq, if SEF is allowed for on-farm use, it can be linked to measures for improved monitoring and irrigation practices, leading to higher water and productivity, and hence higher income and contribution to food security strategies.
- By helping curb groundwater exploitation, SEF can contribute to restoring vital wetlands such as the Azraq basin.

Adapting and mitigating climate change and variability

- Climate change is expected to have negative impacts on crop productivity and production areas of most crops, reducing the total production of most irrigated crops by 27% in 2050 (Al-Bakri et al., 2013).
- In the case of drought and shortages of rainfall, farmers depending on rain-fed agriculture can diversify their income generated by SEF.
- Fossil fuels saved by a wide use of SEF for agriculture, or through the reduction of water use and pumping as a result of improved productivity or substitutions of land use, can help in reducing emissions, thus mitigating climate-change impacts.
- SEF can provide financial opportunities for farmers through global climate fund programmes.

Strengthening green growth and water sector strategies

- Jordan is one of the few countries in the Arab region adopting green policies and a national green growth plans, indicating water pumping and alternative water resources as fields with high potential. (See Government of Jordan, 2017.)
- As suggested by the SEF Azraq project, SEF can be considered as a contribution towards green growth strategies and low economic development.
- As suggested by the SEF Azraq project, SEF might provide significant green jobs in renewables industries for poor farmers. However, this is only the case if farmers are educated and empowered first to enter into new sectors or employment opportunities.

5

SEF IN THE AZRAQ BASIN IN JORDAN

5. SEF IN THE AZRAQ BASIN IN JORDAN

5.1 Project layout and implementation

The "Azraq Basin Solar Farming SEF Pilot Project" (hereafter referred to as Azraq SEF) is one of the pilot projects of the GIZ Regional Programme "Adaptation to Climate Change in the Water Sector in the MENA Region" (ACCWaM)[12]. Box 1 provides a description of the Azraq basin. In this part, key project information is briefly presented.

Project background

- Initiated by the Jordanian Ministry of Water and Irrigation (MWI) (through the Highland Water Forum (HWF), the owner of the idea) and supported by ACCWaM.
- HWF is a network of around 60 key stakeholders in the Azraq basin, established in 2010 jointly by GIZ and MWI.
- HWF put forward recommendations as a groundwater action plan of 2014, including SEF as a measure.

Project idea

- Conventional farming is substituted with solar energy farming, thus reducing groundwater use.
- Farmers are offered an alternative source of income.
- The 2012 Renewable Energy Law No. 13 allowed for selling solar energy at a benchmark price of 0.10 JD/kWh, subject to change by the ministry.
- The new law opened three opportunities to sell solar power: unsolicited proposals, net-metering regulations, and wheeling regulations (see Box 2).
- Azraq SEF was chosen to be submitted as an unsolicited proposal.
- In a 2012 survey, 17 out of 30 farmers expressed willingness to change to solar farming, provided that financial and technical support were provided.

Project implementation

- Feasibility study in 2015, identifying the project as feasible and beneficial.
- Installing a 100 kWp photovoltaic power plant on one Jordanian dunum of farmland generates 180,000 kWh per year, produced by the 100 kWp solar energy power plant at an investment cost of €150,000.
- Gross earnings are €24,000 per year, with a FIT of €0.13/kWh for 20 years.
- Opportunity cost is €250 – the average loss per dunum of annual agricultural net profit.
- Net income by 100% private project financing at 5% interest rate over 10 years = at least €1,000 per year for the first 10 years.

- Consultations with relevant water and energy ministries, as well as the electricity companies, was carried out between 2013 and 2015.
- In 2015, a new bylaw for unsolicited proposals was approved.
- In 2015, the initial selection of farmers and sites was made, along with drafting of an MOU for grant agreement for eventual donor support.
- Co-financing schemes for a pilot farm were outlined and negotiated.

Project outcomes

- The project ended in December 2015 with no pilot plant.
- There was difficulty in establishing an agreement with relevant authorities on power purchase and access to the grid.
- Famers became less willing to implement SEF, citing multiple risks.
- The electricity baseline selling price of 0.10 JOD/kWh changed to 0.055 (€0.065) in 2016, lowering the potential profitability of the project.

BOX 2: THE AZRAQ BASIN

The Azraq basin is a natural wetland with a historically high biodiversity (*e.g.* bird migration) and agricultural values. Since the 1980s, due to over-pumping of groundwater for the supply of urban areas such as the capital city of Amman, Azraq began drying up. As a result, shallow groundwater disappeared together with surface springs. The rapid decline of ground and surface water resulted in the demise of this ecosystem, particularly in the early 1990s. As a result, and due to climate change-related impacts, Azraq was negatively affected by desertification, drought, decline of agriculture, and the decrease of land productivity. Still today, agriculture is overusing limited groundwater, leading to an annual deficit of 32 mcm/year, and a drop rate of water of 80–90 cm/year.

The Azraq Basin currently provides 25% of Amman's potable water, and abstraction from the basin has almost tripled in 20 years. In light of these challenges, several donors as well as government programmes have implemented consultations and pilot projects for aquifer recharge. The HWF is a stakeholder group that aims at catalysing efforts towards sustainable management and restoration. Currently, with no alternative water supply for urban and agricultural supply in sight, the overuse is continuing. The impact on farmers is tangible in terms of increasing salinity and the loss of agricultural livelihoods. Not all farmers, however, are small-scale or family farmers. Small farms date back to the 1970s when refugees in the wave of the Arab–Palestinian war of 1967, and mid-income families, invested in farms as a livelihood or a retirement option (Al-Naber, 2016). Since the 1990s, large farmers invested in olive plantations, expanded agricultural land, and hired professional managers. These farmers represent a powerful group of elites, and are not always in the possession of well licenses or legal land documentations.

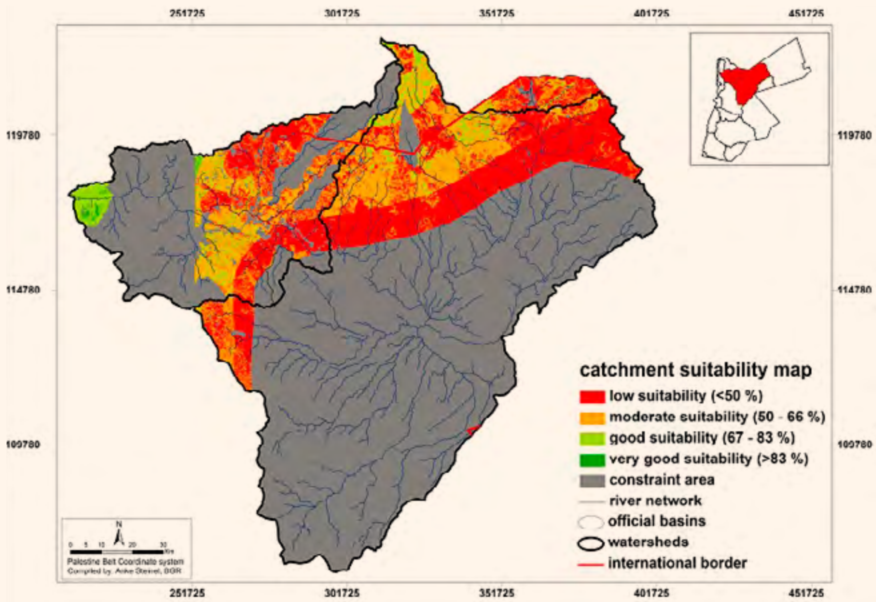


Figure 3: Map of the Azraq basin catchment: Source: www.bgr.bund.de

BOX 3: MECHANISMS FOR DEVELOPING SELLING SOLAR POWER IN JORDAN UNDER THE RENEWABLE ENERGY AND ENERGY EFFICIENCY LAW NO 13 OF 2012

Direct or unsolicited proposals are evaluated by the MEMR following several issued calls for proposal. More recent bylaws regulate the Power Purchase Agreement by the electricity transmission and distribution companies. Heavy competition exists for large-scale utility plants, and therefore the MEMR can annually adjust the selling price. Exemptions for contracts can be given in cases of governmental sponsorship, and under certain conditions. Direct purchase for the government can be an option only if the carrying capacity of the transportation network and the distribution network can tolerate the feed-in energy. This has to be determined by the transmission company and the distribution company.

Net-metering regulations allow any consumer to annually sell excess power at a predefined baseline price in order to reduce consumption, while, in regular cases, not exceeding 100% of the historical annual consumption.

Wheeling regulations are similar to net-metering, with the possibility of off-site renewable energy production and on-site consumption by private consumers. In this case, the payment of wheeling fees and losses is required.

For the Azraq SEF project, the best option identified during consultations was the first one. The other two are related to own consumption and are not oriented towards profitability. Under the unsolicited proposals, an exemption is possible if grant funding, project layout, network capacity, transport, distribution, and the feed-in tariff are agreed on. The project ended without any such agreement.

5.2 Issues and stakeholder analysis

The project's overall idea, contribution and outcomes as depicted in the previous chapter (5.1) represent a complex and multi-sectoral endeavor. The chapter also shows the status quo of project implementation. In fact, the technical feasibility of the project has been shown in a detailed study, and several other studies were commissioned to highlight the positive contribution. However, the project did not move forward with implementation of the pilot project as the PPA for the specific project did not materialise. There are, however, other reasons that contributed to halting the project that mainly lie in the difficult project environment and the participation arrangements. SEF, especially if connected to improved water availability, is typical of potential synergies that can arise from a WEF nexus approach. At the same time, in order to bring out these synergies, the integration of different sectoral regulations and stakeholders with conflicting interests, incentives and powers is highly challenging. This chapter looks at the relationship between issues, stakeholders and participators that might explain the project's failure to move to the implementation phase. The next chapter then provides an outline of key missing issues.

In the case of the Azraq SEF, the integration process of stakeholders and issues posed a major difficulty to analyse here in more details. Table 1 represents a stakeholder analysis partially using GIZ & Lahham (2017). The stakeholders are analysed in relation to the Azraq SEF in three categories: support, power, and project participation modus. The results are shown in the table and will be briefly elaborated on in the following section.

5.3 Explanation of methodology used

BOX 4: LAND RIGHTS IN SOLAR ENERGY FARMING

Solar applications require land space which might not be available to all farmers, while the opportunity costs of this land vary depending on farm size and current use of land. For example, small farmers might not have the required land space, and will have then to buy or rent the necessary land for a SEF application. Land rights and costs vary greatly from one place to another. Furthermore, even if the farmland is unavailable to the farmers, its value should be considered as the opportunity cost in the calculation of the needed SEF investments. SEF investments might therefore be higher for small-scale farmers than for large-scale ones, since the marginal utility of farmland for small-scale farmers is higher. Large-scale farmers might be more willing to give up some of their land for SEF application without suffering big losses or a break-up of their economic livelihood. However, which farmers are more willing and able to engage in SEF activities is difficult to generalise, and should be examined locally through a detailed economic and financial farm analysis.

In the SEF Azraq case, Al-Naber (2016) provides an overview of land ownership and access. Accordingly, land ownership is divided into state land (officially owned by the state by claimed by tribes), lands owned by the state (miri), and private ownership (milk land), as well as many mechanisms to transform public land into private ownership. Illegal land ownership is a problem in the basin, while land prices can be at around 4,500 to 5,000 JD per dunum (1,000 square metres) (Ibid). For the SEF Azraq project, the technical feasibility study was conducted to assess costs and profitability over traditional farming, and required farm sizes for different PV plant capacities, ranging from 5 dunum for minimum size to 200–270 dunum for maximum size (Renac, 2012). In addition, this feasibility study investigated possible locations for the PV installations in the North Badia and Azraq areas, with the possible PV area ranging from 2.2% to 33% of total areas of the sample farms, with only a few to several dozens of dunums being unused for agriculture and available for PV installations (ibid.). Since the pilot project was not implemented due to disagreement over the PPA, there was no study of the impacts of land ownership in the pilot project, or in the Azraq SEF idea as a whole. Furthermore, detailed analyses of farmers' attitudes and capacity needs, as well as financial and economic calculations, were not done, and would be important for the idea to be adopted on a wider scale.

Support.

During the project's implementation, several attitudes of support and rejection were expressed to various degrees. In fact, the core support for the Azraq SEF project stemmed from water sector actors, and was not transferred or shared by actors from the energy sector. As the project initiators, the MWI, HWF and the GIZ were supporting and advocating the idea. The Azraq SEF is a part of the groundwater plan deliberatively agreed on by the HWF. Stakeholders such as the MoE, MoA and civil societal organisations were supporting the push towards greater sustainability in the basin and the key merits of SEF of providing income opportunities while reducing resource depletion. The support of stakeholders such as the MoA was conditional on not harming core agricultural interests in the basin, and was thus moderate and cautious. Banks and investors had a similar cautious but positive attitude. On the one hand, the involved investments and load demand are not big and involve some risks such as the stability of the feed-in tariff and the ability of farmers to build up technical and managerial capacities needed for a successful renewables business. On the other hand, through donor involvement and potential favourable treatment of farmers from energy stakeholders, some entrepreneurial risks might be covered, eventually making the financial support a safe investment.

In the energy sector, the support was low at best. This was explained by the small size of the project, involved high costs of exempting and administrating the project as well as connecting the plants to the network and monitoring the feed. Especially importantly, there was no positive consensus from the farmers on SEF project. Azraq farms are a heterogeneous group of many small farms and, increasingly, large, professional farms (see Al-Naber, 2016). While some surveyed farmers expressed their support for the SEF idea, these were mostly small-scale ones. Large-scale farms are owned by investors and represent the main water users in the basin. The reluctance of farmers, especially large-scale ones, to support the project might be due to the fear of being "forced" to change their livelihood. This is especially difficult for farmers who are indirectly subsidised through illegal water wells and land acquisitions. Furthermore, they were anxious about the business risks and the prospect of being "left alone" with no financial support to cover the high fixed costs involved in developing technical capacities. In total, although there was no outright expression of opposition to the project, the lack of support from stakeholders such as farmers and the energy sector institutions presented a key challenge to implementation.

Importance.

The indicator "importance of the stakeholders'" represents the influence that a stakeholder has on the implementation of the project. This can be expressed by the mandate of the stakeholder, but also through its financial or technical capacities. In this regard, energy sector stakeholders are most important as they can approve and facilitate the pilot plan in the short run. In the long run, they can determine the success of the idea through special regulations for favourable treatment of farmers or grid-related measures. In addition, the farmers, as the project beneficiaries, are especially important. Their collaboration to set up a pilot project is key for demonstrating the viability of the idea and its potential for upscaling. The MWI is also important for administrating and conducting the project, while the MoA can be instrumental for advising the stakeholders. Similarly, the GIZ has a key facilitation role in providing *technical aid, while the banks have important financing and facilitation roles. While the other stakeholders (JREEF, MoE, HWF, and civil society) all have relevant roles at different stages of the project, these roles are rather supportive and dependent on the collaboration of other stakeholders. For example, the JREEF is a financial instrument of the MEMR and presumptively follows the general line of the ministry.*

Participation.

In theory, stakeholder involvement during a project should be designed appropriately for each stakeholder. For example, it should match the relationship between the importance and the interest of stakeholder. Table 2, partially following the participation ladder of Pretty et al. (1995), shows how participation roles were determined. The strongest indicated form of participation during the Azraq SEF project is that of empowerment. Under this form of participation, stakeholders are mobilised and actively participate by taking initiatives. In the Azraq SEF case, this was achieved for farmers and civil society through the active work of the project owners in organising workshops and inviting farmers using the platform of the HWF. In addition, the category of collaboration implies an interactive participation from early on in the process. In this case, the MWI is the most prominent collaborator on the project. Energy sector stakeholders were involved later on in the process through functional participation. This meant forming groups and meetings aimed at solving specific issues, or taking decisions on emergent issues, e.g. the approval of the pilot project. Functional participation also matches the participation of the investors on the financing issue. The next lower category is that of consultation. It implies a process of discussion of problems, solutions, and attitudes without conceding any share of decision making or the need to incorporate the views of the other. In this case this can be ascribed to interactions with the MoA and the MoE.

Stakeholder		Interest	Role	Support High ++ /Low - -	Importance (power) High ++ / Low - -	Participation format during the project
Public Stakeholders	**Ministry of Water and Irrigation (MWI)**	Abstraction reduction; no interest in co-funding	Project owner; regulation of groundwater; selection of farmers and disbursement of future Azraq SEF project funds; monitoring farmers' water commitments; coordination with MERM and cabinet	++	+	Collaboration
	Ministry of Energy and Mineral Resources (MEMR)	Steering renewable projects towards achieving the 10% target for 2020	Selection and approval of projects; regulations and policies in support of the renewables law and national strategy	-	++	Functional participation
	National Electric Power Company (NEPCO)	Diversification of power generation capacities	Power off-taker; issuing of project licence in coordination with EDCO	-	++	Functional participation
	Electricity Distribution Company (EDCO)	Grid stability	Feed-in grid operator; issuing connection permits; monitoring the feed-in	-	++	Functional participation
	Jordan Renewable Energy and Energy Efficiency Fund (JREEEF)	Financing competitive renewables projects	Established by MEMR; funding mechanism for renewables and efficiency-based projects	-	-	Consultation
	Ministry of Agriculture (MoA)	Supporting farmers and sustainable agriculture	Awareness programmes; increasing water productivity and use efficiency	+	+	Consultation
	Ministry of the Environment (MoE)	Supporting renewables projects	Issuing environmental licences after an environmental impact assessment	++	-	Consultation
Donors	**GIZ**	Promoting Azraq SEF for its water-saving potentials	Facilitating project implementation through grants and collaborations with stakeholders	++	+	Project owner
Private Sector	**Banks/ Investors**	Profitable outcome for the Azraq SEF project	(Co-)financing of Azraq SEF and any future projects in the event of good feed-in tariffs of profitability	+	+	Functional participation
Farmers	**Farmers with large and small holdings**	Sustaining income and own livelihood	Plant owners or tenants; recipients of income; committing not to pump water	-	++	Empowerment
User associations	**The High Land Water Forum**	Groundwater management in high lands	Offering insights on the specific needs, living conditions and livelihoods of the affected farmers; HWF as a governmental body at the MWI	++	--	Project owner
Civil Society	**Civil Society (*e.g.* green pioneers[13])**	Promoting green economy and renewables	Previous work in capacity building of farmers and public institutions on renewables	++	--	Empowerment

Table 2: Stakeholder analysis in the Azraq SEF project

In order to understand the incentives and attitudes of the stakeholders involved in the Azraq SEF project, it is helpful to analyse them further. Figure 4 depicts the key stakeholders using two composite categories, importance and interest. Interest is understood here a measure of a private cost–benefit calculation of each stakeholder. In this sense, each stakeholder weights rationally the potential benefits from the project against his/her expected costs. In plotting these categories against each other, one can better understand the cautious attitudes of certain stakeholders, and the high support from others. For the MEMR, EDCO and the NEPCO, there were no obvious benefits provided while they were asked to administrate a project that is probably less competitive than other large-scale proposals for utility solar farms. Furthermore, big famers have low interest due to the lack of assurances about the future benefits. The adaptation costs, the high capital investments and the perceived loss from committing themselves to water-use reductions outweigh the benefits in the short term: *i.e.* having more profits per hectare. This is especially true for large farmers who are comparatively profiting more from water abstractions and the illegality surrounding land and water-use conditions (see Al-Naber, 2016). For the cautious stakeholders such as investors, the MoA and small-scale farmers, there are good benefits for each one of them (*e.g.* profits from SEF, sustainability in agriculture, higher income) but also some risks (*e.g.* project failure, demise of agriculture, lack of support). For the other stakeholders such as HWI, MWE, MWI, and donors, there are many tangible benefits in terms of being able to fulfil their mandates of promoting sustainability in the water sector and the Azraq ecosystem.

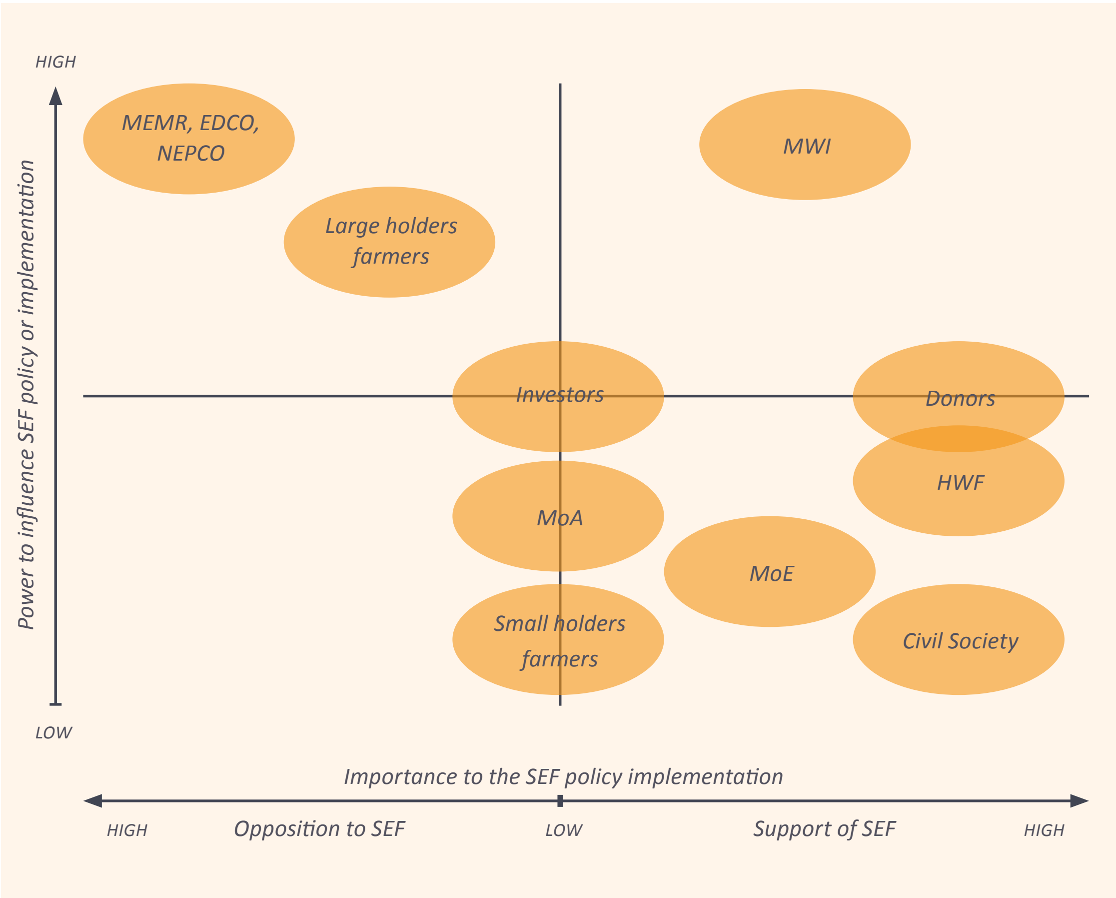


Fig. 4: Relation between Power and interests of stakeholders

In order to understand the interests of stakeholders one needs to analyse the core issues involved in the debates and negotiations during the project. Figure 5 shows the result of this issue analysis. The issues and the stakeholders interested in them are briefly described here:

Grid extension to Azraq.

Effectively, if the Azraq SEF pilot project is implemented and upscaled, this would require connecting several SEF projects to the power grid. Potentially, if arrangements under net metering are to be favoured, this could also involve the need to connect many scattered wells, installed with solar pumps to the grid. This is also required in the case of many small SEF plants. While this issue might be of interest to the farmers in order to enable them to implement the project, it is not directly of interest to the MEMR and NEPCO, and arguably not for EDCO. The MEMR and NEPCO might favour such a grid extension partially for rural development and electrification reasons, but it is not beneficial for EDCO due to expected costs and grid instabilities. Note that due to the increase in renewables projects in Jordan, the current grid capacity is on the limit, and is currently being extended by a capacity extension project in the South, the so-called "Green Corridor Project"[14].

Maintaining grid stability.

This is of interest for all energy stakeholders, but importantly, it is not a key issue for the others. This might be one indication of the challenge to get the support of the energy sector.

Finding competitive renewables project.

This is another major interest of the energy stakeholders. It is, however, shared by the banks and the MoE, which promotes renewables as a green and environmentally friendly energy source.

Giving subsidies to farmers.

These subsidies can be the water subsidies through illegal water wells (no licensing fees or water use price) or through water used below the full marginal price of water, and any subsidies to SEF projects. Such SEF subsidies can emerge from co-financing or granting parts of the fixed costs, or by a favourable feed-in tariffs. This interest is a fundamental one for the farmers, but not shared by any other stakeholders as their own interest.

Reducing water abstraction.

This is a core interest of all water stakeholders, and partially shared by the MoA. The MoA favours sustainable agriculture while preserving overall agricultural productivity. At the same time, this issue does not present a mutual interest with the energy stakeholders.

Improving income of farmers.

This issue is of mutual interest between the farmers, GIZ, civil society, the banks, and the MoA, but is not an important issue for the energy sector, and also not for the MWI.

Building capacities of farmers.

This is a central issue for civil society, GIZ, the MoA and farmers. It is also of interest to the banks since it improves the projects' success.

In analysing the stakeholders and their interest in the key issues, it becomes clear that there is divergence among water, agricultural and energy stakeholders on sector-driven issues. In the Azraq SEF case, this is most evident between the water and energy sectors, where the water sector has nothing tangible to offer for the energy sector to come on board. At the same time, stakeholders such as the MoA, the MoE and the investors have some important links on both sides. Theoretically, empowering these actors as mediators, and working with them to be the linking element in a win–win arrangement for the Azraq Basins, can be beneficial for the project success.

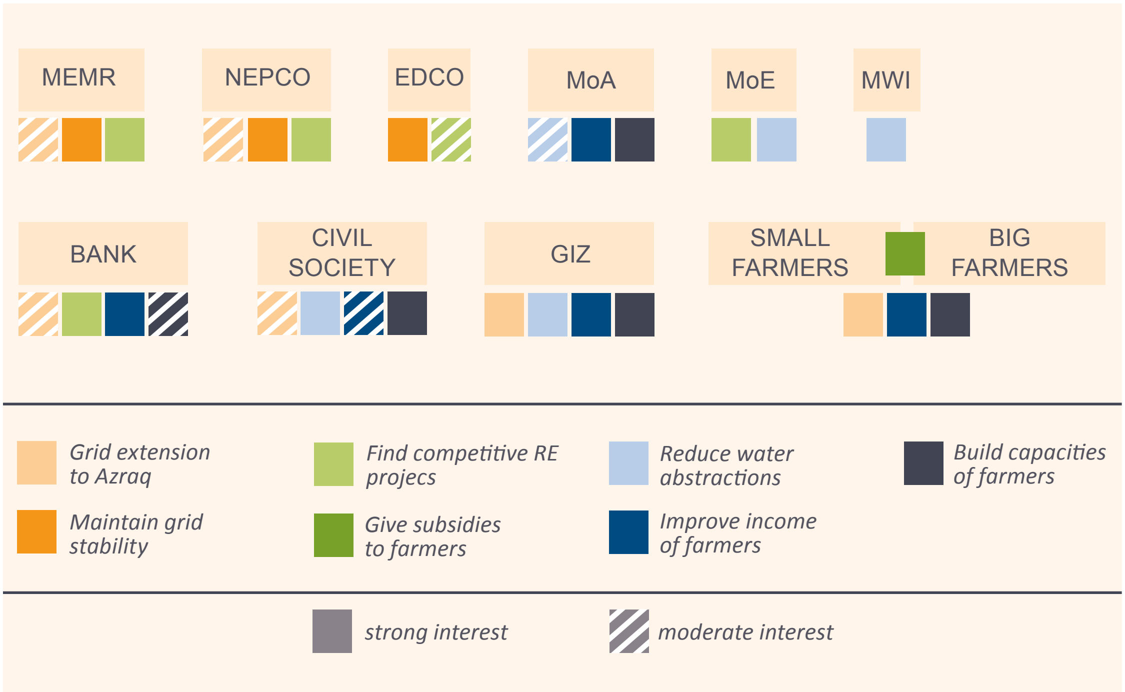


Fig. 5: Issues' analysis in the Azraq SEF projct

5.4 Evaluation of critical links and policies

Based on the analysis of stakeholders, incentives, and issues, one can outline some initial insights by identifying the missing links to be addressed and the opportunities to be seized. This is presented in the following section. The missing links are described by both looking at the project implementation process and also analysing contextual factors in the project environment. The opportunities are stated with reference to policies and institutional interplays in the current *status quo*, and by referring to prospective reforms. It is important to note that the opportunities outlined represent initial lists of issues that require further study and in-depth discussion. They are not presented as recommendations, but rather as conceivable solutions based on the prior analyses.

Project-internal missing links

1. Lack of convincing strategies.

The apparent lack of interest or support from key stakeholders from the energy sector or large farmers can be addressed by developing specific convincing strategies, stating specific cost–benefits, immaterial gains, and spillovers from the project on their preferences. Requests for assistance without the prospect of gains can lead to resistance in cases of stakeholders driven by self-interest. The convincing strategies for energy stakeholders can be achieved by addressing other missing links while linking the project to broader sectoral goals, e.g. rural electrification, increased resilience through decentralised approaches, etc. (See points 2, 3, 4, 13, 15 and 16 in this regard.) Similarly, a convincing strategy for large farmers need to be developed. (See points 4, 8, 10, 11, 12, 13, 14 and 18.)

2. Underrepresentation of societal welfare and impacts.

The overarching goal of the project is the reduction of groundwater abstractions. Arguably second in importance are the income opportunities for farmers. The societal and welfare spillovers from these targets were not adequately quantified and incorporated into the convincing strategies. The feasibility study is limited in focus, i.e. project profitability from a famer perspective and technical feasibility of implementation (e.g. site or size). This does not provide broader data-based numbers of anticipated impacts of the project. Such an exercise can provide valuable arguments for the need for cross-sectoral collaboration and innovative regulatory solutions. The Azraq SEF project has an ambitious agenda of contributing to reductions in fuel subsidies, savings of economically valuable water resources, jobs through structural change, improved livelihoods and ecosystems, etc., although the overall convincing strategy centred on the financial feasibility of the project. This is important for individual farmers, but from the point of view of energy stakeholders, this is rather a weak argument if the Azraq SEF approach is compared with utility-scale solar projects.

3. Unbalanced participation strategy.

Stronger participation strategies towards key stakeholders such as the energy and agriculture sectors can increase ownership of the project idea, and might result in a better level of support. The participation was rather functional and irregular. More participation, whether through the HWF, or even better as project owners, might be helpful. The stakeholders mentioned are both *important stakeholders for the project and powerful institutions in general. Innovative ideas such as the SEF Azraq basin are an example of WEF Nexus dynamics where the water sector is the most vulnerable one. Water sector practitioners seeks collaboration to ease the pressures on their sector. In order to succeed, the water sector needs to convince other sectors to step up beyond familiar boundaries. This might not always be possible, but a higher level of empowerment of other sectors is a necessary requirement.*

4. Risk ambiguities.

Ambiguities existed regarding the financial risks related to the pilot project, risks related to continuation of water abstractions despite the projects, and the costs associated with the grid regulation and connection. These risk categories were not decided on or regulated. As a result, stakeholders were less willing to give their support. For example, farmers desired assurances for preferential treatment and capacity support in the start-up phase. A similar interest was found with investors. Furthermore, energy stakeholders doubted the high grid-related costs for the small project scale. At the same time, it is difficult for the MWI to promise that reducing abstractions will be fulfilled after implementation, especially considering that it has little leverage over farmers. While these risks cannot be outsourced completely, they can be clarified through risk-sharing agreements. Moreover, considering the innovative nature of this pilot project, leadership is important. Such leadership should be willing to accommodate large portions of risks for demonstrating the way forward. Risks can also be addressed through better cooperation and institutional arrangements. (See points 12, 13, 15, and 16.)

Missing links in the project's context

5. Lack of a cross-sectoral integration mechanism.

Four ministries along with their specialised agencies were involved with no clear institutionalised mechanism for arriving at a decision. This is a fundamental issue required for facilitating cross-sectoral projects. There are ad hoc forms of cross-coordination such as inter-ministerial working groups and committees. However, these are task-driven (e.g. development of a joint agriculture–water strategy), and lack real powers such as initiating, approving, or exempting projects. The lack of a clear instrument leads to confusion about who should take the decisions, who should lead, and based on which authority. As a result, decisions are referred to higher levels, e.g. ministers and cabinets. This leads to a delay and no decisions, as the Azraq SEF project shows. Even if a decision to support a project is made at higher level, such a decision does not solve the procedural issues. The questions of who takes implementation decisions and who acts as the lead authority are not resolved. This report presents some solutions for future projects. For example, establishing an authorised body, e.g. a task group or committee, for the facilitation of prioritised projects might be helpful. There is already a task group on water–energy issues, but its decisions are not binding. Such solutions are therefore not long-term oriented, as it is impractical to initiative an irregular, exceptional procedural arrangement for each project, whether small or large. A more sustainable solution would entail detailed regulations on coordination procedures and decision-making in issues concerning different ministries.

6. Lack of project legacies.

The Azraq SEF project is a pilot project that has different goals than projects envisioned under the renewables law. The novelty of this project, as well as of renewables projects in general, represented a challenge. The involved institutions did not have relevant experience to build on, whether in administrating or implementing the SEF project.

7. Policy orientation towards economisation.

The Azraq SEF project is oriented towards social policies such as supporting farming and reducing water overuse. In this regard, solar energy production and its contribution to the increase in renewables is seen as an instrument. In this sense, the project is not in direct accordance with the overarching goal of pushing renewables to economise on large-scale applications and increase energy efficiency. In fact, renewables policies, together with the green economy agenda in Jordan, emphasise the role of the economy and the private sector, and are less oriented towards social welfare, social development, or small-scale renewables projects. The required exemptions for the Azraq SEF project invoke social considerations and some forms of subsidisation, something not adequately provided by current policies.

8. The dominance of the interests of large-scale farmers.

Agricultural interests, especially of large farmers, are very strong in the Azraq basin and elsewhere in Jordan. Public stakeholders were reluctant to engage in projects that would threaten these interests in terms of curbing unsustainable agricultural, changing water regulations, or increasing monitoring and enforcement. In addition, water-sector stakeholders advocated that farmers practising illegal water and land use (usually large farmers) were not to take part in the project. This would have led to even greater resistance from this powerful group.

9. Unsustainability incentives.

Water and energy subsidies play a major role in the decisions of farmers. Farmers do not pay the full production cost of water, let alone the additional costs of increasing scarcities and externalities required for a full cost calculation. Similarly, energy is subsidised, which changes the cost–benefit calculations of renewable projects. These subsidies make innovations and projects based on renewables less attractive. They are also not targeted based on farm size, consumption level, income, etc., with the result that large, wealthy farmers end up receiving a larger share of subsidies. This is a recurring problem of water and energy subsidies in many regions, and requires a reform of pricing policies.

10. Underdeveloped capacities.

Farmers lack the technical and managerial knowledge to engage in renewables projects, and require support in this regard. This is even more important if they need to compete with professional endeavours in highly attractive renewables markets. Besides, involved public institutions lack the capacity to monitor and administer cross-sectoral projects. The current capacities are sector-oriented and not flexible enough to be integrated into multi-issue and multi-sector projects. Any lead institutions for the project would require expertise in different sectoral aspects, and should thus be offered training and support. This is especially true for developing project guidelines, policies, and monitoring instruments in order for SEF to achieve a positive contribution *to groundwater quantity and quality. In this regard, intermediaries such as extension services, and private sector companies offering advice and services to farmers and farmer associations, can play a positive role in developing capacities.*

Opportunities under current arrangements

11. Partnerships and coalition.

There is an opportunity for rearranging stakeholder roles to achieve a better level of support. Using the analysis of issues involved in the Azraq SEF project, stakeholders such as the MoA, the MoE and the investors share key interests with other stakeholders, and can thus help build crucial links. For example, the MoA can be instrumental in convincing farmers, building their capacities, and thus giving investors and the energy sectors some reassurances about the profitability of the projects. This role of agricultural actors is feasible when the project links to irrigation and agricultural issues and does not exclusively focus on substituting traditional farming. Furthermore, the MoE represents an important link between the energy and water stakeholders on the issue of renewable energies. It can promote closer collaboration and mediate concerns if empowered and offered enough incentives to participate. Such stakeholders are important to partner with and build issue-based coalitions. This might require increasing the issues to be targeted by the projects in order to accommodate the interests of these stakeholders, e.g. agricultural practices, cropping patterns, irrigation, aquifer recharge, etc.

12. Institutional arrangements for farmers' cooperation.

The institutional arrangement among farmers can be important for addressing financial risks of the project, but also for regulations on effective control of water use. For example, farmers can organise into cooperatives in order to share the risks and the investment costs. As mentioned in this report, there are other forms of organisations which require further analysis. The advantage of these arrangements is that they help to alleviate some concerns on the part of farmers, investors, the MWI, and energy stakeholders.

13. Improving competitiveness and bankability.

Ways to increase competitiveness in applying for the pilot project can be explored. Farmers or farmer associations can compete for support in establishing the pilot project, e.g. by citing their managerial experiences or commitments to increase water use efficiency and reduce abstractions. It is also conceivable that different locations in the Azraq basin or Jordan can compete for the project via local administrative bodies. Furthermore, assurances about willingness and ability to share financial risks of the project can be requested.

14. Promotion of best practices and capacity building.

Best practices and similar experiences in the Arab region and internationally can be promoted as a part of the convincing strategies and the capacity-building efforts in the project. This can help to address concerns about the risks related to the novelty of the approach, and promote the idea in a larger context of sustainable development.

Opportunities under future reforms

15. Multi-donor approach.

A multi-donor approach might help in sharing the large administrative and financial efforts needed for SEF projects aiming at large cuts in water use. In the event that mechanisms for cross-sectoral integration in Jordan are improved, a multi-donor approach can increase emphasis on and prioritisation of the idea, while also addressing the multiple missing capacities.

16. Using economies of scale.

Arguably, a major obstacle to support for the project was its small scale. A larger investment in, for example, a utility-scale farm with the ability to provide an alternative income for a large number of farmers can be more effective for reducing groundwater abstractions. Furthermore, such larger SEF project will lead to economies of scale by decreasing the fixed portion of total costs. This option needs first to be adequately explored, however, under the condition that renewable regulations become clearer regarding the approval and administration of such cross-sectoral development projects. Moreover, considering the larger requirement of land for such a project, adequate institutional mechanisms such as the participation of farmer associations and community-based ownership might be necessary.

17. Promoting smart or more integrated solution.

It is worthwhile exploring options to integrate SEF with other ideas. As stated before, other SEF projects link subsidisation of solar energy to irrigation and water-efficiency technologies. in addition, SEF can be linked to water harvesting infrastructure. These arrangements help to provide clear commitments on sustainability of water use. There is also no limit on innovations regarding the use of the solar energy produced. For example, it is conceivable to use the energy for small-scale water reuse or desalination applications, or other productive uses such as chilling. With regard to these smart or innovative ideas, one key challenge that needs to be addressed first is the pricing issue, since low energy and water subsidies can make some applications not viable

18. Exploring community-based solutions.

The community can be an interesting scale for the management of SEF projects, but also as a beneficiary group. The community, whether a village, a district, or a user association, etc., needs to accommodate agricultural interests and promise some potential of water use reduction. In the Azraq basin, this will probably be on a small scale, since the big water users and large farms are not confined to a specific community. Nonetheless, a community perspective could provide interesting insights, such as the viability of community solar farms where local consumers can contribute by buying shares. (See US Department of Energy, 2010). Another idea requiring careful analysis is that of water or solar energies as services provided by farmer cooperatives.

BOX 5: THE ISSUE OF WATER PRICING IN JORDAN

Inefficient pricing policies encourage overexploitation of groundwater resources and reduce incentives to reduce consumption. Similar to countries with high water scarcity conditions and thus increasing marginal cost, reform pressures to improve, above all, efficiency and cost recovery are increasing. Water pricing thus plays an important role in facilitating future change towards demand management and sustainable use, and can increase the contribution of projects such as SEF Azraq in reducing groundwater use. However, solving the problem of water pricing is beyond the scope of this project and requires political commitment.

The current water pricing scheme often does not lead to cost recovery. Water-related subsidies constituted 20% of the government deficit in 2010 (OECD, 2014). In the agricultural sector, cost recovery can be as low as 50% of O&M costs, and only one third of the full cost of irrigation (FAO, 2004). The agricultural pricing schemes have undergone various reforms recently in order to increase the tariffs and punish illegal wells through higher tariffs. At the same time, famers still have some influence over pricing reforms, and can decide not to pay. (See Al-Naber, 2016 for an overview of the pricing situation in the Azraq basin.) Although the collection rate of billed water is high in urban areas, in the agricultural sector utilities might fail to follow up on customers' debts. In general, water used for agriculture is not priced at full environmental cost, which includes the incorporation of scarcity, environmental degradation, and externalities, while the pricing policies are largely oriented towards equity and affordability considerations (Al-Assa'd & Sauer, 2010; OECD, 2014). Solving this issue of adequate pricing can remove many distortions and make projects with positive outcomes on water efficiency more viable. The main obstacle here is not finding the right pricing policy, but rather the political will and feasibility to do it despite opposition from farmers. One can therefore expect no quick fixes in the short term for this overarching problem.

6

SEF IN THE INDIAN CONTEXT

6. SEF IN THE INDIAN CONTEXT

6.1 Case context

The aim of this report is to provide insights that can help advance the SEF Azraq project and similar projects in the context of Jordan and the wider Arab region. The basic idea of encouraging substitution of traditional farming livelihoods for livelihoods as solar farmers is indirectly reflected in other international SEF experiences such as in the Indian case. Although this idea of substitution is not the motivating factor behind SEF experiences in India, it is reflected as a secondary goal in many of recent projects as described below. In fact, SEF in India is centered around agricultural modernisation through the use of various kinds of applications such as solar pumping systems (SPSs) and solar-powered irrigation systems (SPISs). Note that SPISs imply more than the use of solar pumps for irrigation, as they include a higher level of harmonisation between pumps, irrigation components, and crop requirements[15]. This is not always the case with SPSs, and there is evidence in the Indian case of oversized systems as a result of high subsidisation and the lack of enforcement. The cases presented below focus on SPIS and SPS programmes where either a PPA is pushed, or these systems are linked with objectives regarding reduction of groundwater abstractions. This selection is made in order to allow for comparison and the development of insights into technological and institutional options that can advance SEF in Jordan. However, all of the projects and programmes represent SEF as combined systems: *i.e.* solar power linked to either irrigation or water issues such as recharge. There was no case found that resembles the SEF Azraq idea of SEF as a stand-alone system run by farmers as an alternative livelihood with no possibility of using produced power for on-farm activities. However, in the presented cases with a PPA, farmers can theoretically decide to sell the entire power surplus, which would eventually achieve the same aim as SEF Azraq.

6.2 Projects and impacts

India’s experience with SPSs and SPISs is vast, dates back to the early 1990s, and still represents a controversial issue with regard to the impacts on vulnerable water resources such as groundwater. Groundwater usage has become the main source of irrigation in India (61% of the net irrigated area in 2011), since the deterioration of irrigation infrastructure as well the increase in rural electrification made farmers turn to groundwater[16]. Groundwater use has increased significantly in the last decades (Figure 6). Agriculture continues to be the major employment sector in India – around 45 % of total employment in 2017 according to the World Bank databank. The government therefore encourages solar power use in agriculture, providing up to 95% subsidies to capital costs of SPSs. This policy is motivated by improvement of rural development and farmers’ income, and by the fact that irrigation pumps – around 20 million, of which 9 million run on diesel – and the agricultural sector account for 22% of total electricity consumption (Agrawal & Jain, 2016).

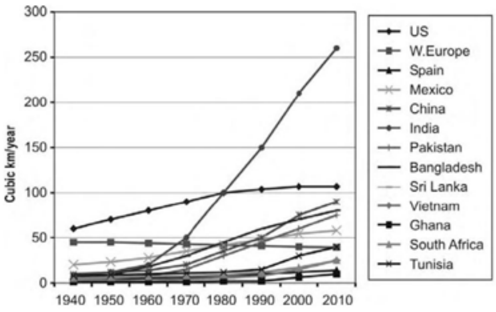


Figure 6: Groundwater use increased susbstantially in India since the 1960s. Source: Shah (2005)

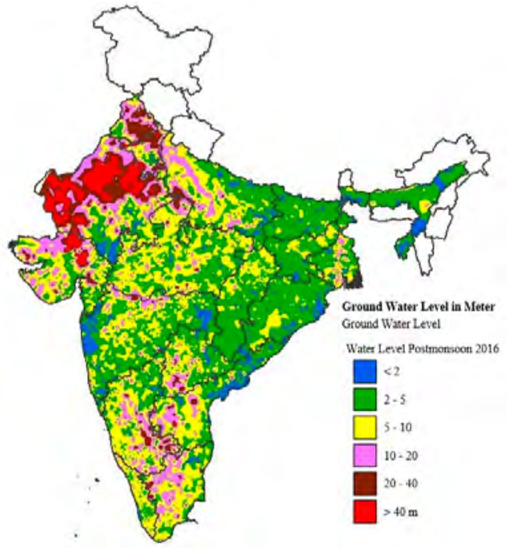


Figure 7: Groundwater level in India reflects overexploitation mainly in North-Eastern and Southern parts. Source: www.india-wris.nrsc.gov.in

The number of SPSs in India is increasing, and targeting both groundwater and surface water irrigation. In 2015–16 alone, more than 30,000 solar pumps were installed, more than the number of pumps installed in the last 25 years[17]. This is a reflection of growing public investments in SPSs, as well as the increased attention from donors to developing more integrated projects, *i.e.* linking SEF to efficient water use and agricultural practices. Some interesting cases will be presented in the following highlighting debates and projects aiming at linking SEF to groundwater use. This represents a rather new trend. Previous efforts were oriented towards the empowerment and education of farmers and the optimal use of land (*e.g.* GIZ, 2013). The education of farmers and the development of technical capacities for operating SEF applications is one of the most important challenges facing SEF applications in India. Furthermore, groundwater protection is especially urgent in water-scarce regions in the North East and the South (Figure 7). According to Bassi (2016), the SPSs policies are starting to change focus. In the past, they centered on increasing subsidisation of SPSs, cheap energy, and equitable access to groundwater. In contrast, scholars now emphasise options to directly or indirectly protect groundwater through solar systems, *e.g.* tradeable water rights, *pro rata* pricing systems, and SPSs with drip systems. The reason for this change is the criticism of previous projects, which led to oversized SEF installations, and lacked enforcement mechanisms regarding SEF use for water abstraction.

Solar farming and solar irrigation pumps in India

The State of Gujarat

In the state of Gujarat, agriculture is an important electricity demand sector, responsible for around 25% of grid electricity usage (Dekker, 2015). In an effort to reduce the burden on power plants and increase electrification, the government has long been involved in subsidising solar pumps. For example, in 2014 1,000 off-grid pumps were given to farmers at the nominal price of up to $80 for a 3HP pump[18]. In 2017, after already having installed 20,000 such pumps, the government halted a tender for 5,000 solar pumps, each at around $55,000 with a subsidisation rate of 90%, due to unavailability of funds[19]. In fact, the rise in solar energy pumping has raised concerns about groundwater depletion in water-scarce states, leading to innovative projects using the cooperative models. A promising project was initiated by the International Water Management Institute (IWMI) with the Sir Ratan Tata Trust[20]. In this project, a Solar Pump Irrigators' Cooperative Enterprise (SPICE) was developed consisting of six farmers in Dhundi village. The surplus from the six net-metered pumps, with a total capacity of around 56 kWp, is sold to the local power utility. Importantly, the cooperative signed a 25-year power purchase with the power utility at the rate of around $0.07/kWh, resulting in estimated earnings of around $4,700 a year for the cooperative from selling surplus energy – in contrast to the initial total cost contribution of $80[21]. In this way the farmers payed a very modest contribution to the costs of the grid as well as the pumps. In addition, the IWMI-Tata programme provide a Green Energy Bonus and a Water Conservation Bonus, bringing the total feed-in tariff to $0.11/kWh. The project has resulted in some tangible results with regard to improved income and decreased groundwater abstractions (Shah et al., 2016). The project presents a win–win situation due to its benefits for both farmers and the state energy companies. Note that the government's benefits are tangible in terms of saving subsidies from the supply of highly subsidised grid power at around $0.011/kWh. IWMI has previously implemented pilot projects with a guaranteed buy-back arrangement under the "Solar Power as a Remunerative Crop" programme in the Anand District of Gujarat[22]. This programme implemented solar pumps at selected farms using funds provided by IWMI, proving the viability of the idea on the farm level[23]. The approach to combining efforts in cooperatives or similar arrangements can help to optimise capacities and reduce costs (IRENA, 2016). There are other examples of water cooperative arrangements. In the state of Bihar, a pay-as-you-go model was established as a business model of providing "water as a service". Water user associations cooperate with a private company, Claro Ventures, for the operation and management of a solar pumping system. They charge government-fixed irrigation fees and have the task of irrigation optimisation, thus supporting farmers while releasing them from performance risks and high up-front costs (Shim, 2017). The operators of this system of community tube wells are the persons who donated private land and are responsible for serving a group of eight neighboring farms organised into associations (KPMG, 2014).

Karnataka State

There are around 25 million irrigation pump sets in Karnataka, which use up to 40% of the state's power and require substantial subsidies (around $1.14 billion in 2014) for the practically free and unmetered supply of electricity (Sudhakar et al., 2014). Realising the potential for savings of subsidies and improving the status of groundwater, in 2014 the government launched the Surya Raitha programme. This programme promoted grid-connected solar irrigation PV pumps on a net metering basis through a 90% cost subsidy and a feed-in tariff of around $0.15/kWh for non-subsidised plants, and around $0.11/kWh for subsidised ones. The programme aimed at supporting 10,000 pumps[24]. In this case, the government is providing subsidies for systems up to 10 HP, which would require a capacity of 10 kWp. The programme is promising, as it can help adapt to the increasing and persistent droughts as well as groundwater depletion in the state (Fishman et al., 2016). According to Shah et al. (2014), in the Karnataka case as well as in other cases such as in Bihar, such high subsidisation might not be necessary. Nonetheless, the arrangement with cost subsidies and a guaranteed payback have several advantages, *e.g.* improving farmers' livelihoods, a built-in incentive to conserve water, and reducing transmission and distribution losses by replacing grid power by local power (ibid.). The programme experienced some delays. Major difficulties lay in financing the large subsidisation committed by state institutions and co-financed at national level, as well as in the administration of the tendering process for the large number of promised pumps[25]. The first reported project was the installation of a solar power system with a dedicated feeder in the Harobele village near Kanakapura in late 2017[26]. Considering the large scale of the initiative, the continuation of the programme could lead to tangible water reductions.

Rajasthan State

Rajasthan has the highest potential of solar power in India of around 142 GWp (Bassi, 2016), but is also a groundwater-vulnerable state. Most water is used through flood or furrow irrigation methods, using so-called *diggis* (ponds) via pumps and distribution networks. In the long run, this has negative impacts of groundwater recharge, something the government aimed to counteract with programmes to construct additional tanks and diggis[27]. Rajasthan has an extensive solar pump programme which aims at improving the livelihoods of farmers while linking solar pumps and water harvesting. The programme is a collaboration between state institutions from the agricultural and energy sectors. The subsidised pumps are stand-alone and thus not connected to the grid, and rather target remote areas. The government requires farmers to deploy drip-based micro-irrigation systems that have 90% water-use efficiency compared to the 30–45% of flood and furrow methods (Goyal, 2013). During the selection of farmers to be subsidised, the availability of a diggi and the purchase of a drip irrigation system were formal requirements. According to Kishore et al. (2014), the programme had some benefits but also some flaws. While farmers replaced their diesel pumps with solar ones, leading to decreased costs, emissions and labour costs, medium and large farmers were the main beneficiaries. Furthermore, the adoption of drip irrigation seemed to increase in the state, but neither did the new demand for electricity connection nor groundwater use decrease, and there is also no insurance that the farmers will not use the solar pumps for flood irrigation (Tewari, 2012).

Odisha State

Odisha is vulnerable to climate change due to monsoon variability, leading to climate extremes and affecting groundwater availability. An innovative project that was approved in mid-2017 under the Green Climate Fund with a total investment of $166.3 million, is "Ground Water Recharge and Solar Micro Irrigation to Ensure Food Security and Enhance Resilience in Vulnerable Tribal Areas of Odisha"[28]. The project is expected to have tangible impacts on around 5.2 million people by linking community-based rainwater harvesting measures (recharge shafts in 10,000 tanks) and improved irrigation schemes through the use of 1,000 solar pumps. While the project does not envision selling power, it is indicative of the future direction for SEF projects in India, namely the close integration between solar energy, sustainable irrigation, and water conservation.

West Bengal State

West Bengal suffers from the low development of irrigation capacities and from climate variability. As a result the World Bank has implemented the $300 million "West Bengal Accelerated Development of Minor Irrigation" project[29]. As a part of this project, hybrid solar photovoltaic systems for pumping purposes are equipped with a GPRS wireless modem thus automatically transmitting data on flow and energy use. This data can be viewed through a Web-based system and also used by regulators. The project also explores water-as-a-service models where payments are based on actual use of water delivered by pumps[30].

6.3 Contextual issues

The cases presented have identified new trends and innovative approaches for SEF and SPSs in the Indian context. In order to understand the much more comprehensive experience in India, some crucial issues are highlighted in the following section:

Public commitment.

Solar energy in the agricultural sector is a part of a bigger effort in India to promote solar power, achieving 100,000 MW of solar power by 2022 under the Jawaharlal Nehru National Solar Mission (JNNSM). The installation of 100,000 solar pumps under the National Mission on Sustainable Agriculture for irrigation and improvement of drinking water for around 7,600,000 poor families is linked to this goal. At least a 30% capital subsidy is provided by the Ministry of New and Renewable Energy (MNRE), while state agencies can provide additional subsidies[31]. It is worth while noting that the programme of MNRE for promoting solar pumps is long-standing. Since 1992, the use of solar pumps has been encouraged with the help of state agencies providing subsidies of up to 90% of total costs. Donor organisations are involved in many projects, and recently collaborated with the government on more integrated or smart approaches, and also on building the capacities of farmers.

The lack of awareness of farmers on SEF technologies and the lack of knowledge on maintenance of the systems and irrigation practices presents key obstacles for the economic and social sustainability of SEF in India (Agrawal and Jain, 2016). These critical issues require more public efforts in the future.

Diversity of approaches.

There are different design approaches for solar pumps in India. MNRE (2014) listed five different systems: a) grid-connected pumping can be arranged with a pay-back agreement with electricity authorities for power surplus; b) solar pump mini-grids aim at separating power for residential power from irrigation pumping in rural areas. Electric pumps are coupled with a transformer-based PV plant ranging from 25 kWp to 500 kWp and feeding several pumps, while the system can be under a joint ownership of the community, public institutions, or the private sector; c) replacement of diesel pumps with solar pumps in off-grid areas; d) community-based or water-as-a-service systems where either portable solar pumps are shared or communities, sometimes with enterprises, offer water services using solar power; and e) micro-solar pumps with less than 75 Wp to 500 Wp are promoted for farmers with very small land plots.

Adverse subsidies.

The promotion of solar pumps in India was financed by high subsidisation of costs. These subsidies are criticised for several reasons. Firstly, no linking the use to sustainable practices has often resulted in groundwater depletion, especially by large and medium-sized farmers who had the larger share of subsidies (e.g. Bassi, 2016, 2018). Furthermore, the subsidies are given on a pro rata basis: i.e. a percentage of total costs. This makes farmers choose more expensive models with higher capacities, thus leading to more water abstractions. In addition, this system is not as efficient as a lump-sum system since it hinders competition and dissemination of SPSs (Kishore et al., 2014; Shah et al., 2016). Reducing the subsidies can also free up resources to support more farmers.

Another potential adverse effect is that of the high feed-in tariff. In some cases where the guaranteed feed-in tariff is very high, e.g. up to $0.15/kWp under the Surya Raitha in Karnataka, this subsidy might lead to inappropriate incentives. If there is no reliable net-metering of the evacuated power, farmers might use the solar plant to sell all produced power to the grid and use diesel or electric pumps for irrigation, or even feed the grid with power produced with a diesel genset. (Shah et al., 2014).

Cost/benefits debate.

The debate about the costs and benefits of SPSs in India is undergoing. While there is a common sense about the adverse effects on water resources of previous subsidy programmes promoting cheap access to solar energy for irrigation, newer policies such as the payback guarantees are still controversially debated. Alongside the criticism of the high and, for some people, unnecessary subsidisation of the feed-in tariff as well as the capital costs, some criticise the inefficiencies of small-scale plants for solar pumps as well as the high infrastructure costs for connecting them to the grid (see Bassi, 2018). Such costs could be higher than alternatives for reducing water use, such as universal metering of agro-wells. However, such a cost–benefit perspective neglects the political and social impracticalities of enforcing water metering and payments by farmers in many developing countries. Providing incentives for farmers to change their ways by capitalising on a better income alternative seems a promising idea to break the decades-old gridlock of non-cooperation by farmers. Furthermore, SEF schemes can provide additional, often unconsidered benefits in terms of saving subsidies for cheap electricity, rehabilitating the health of ecosystems, improving the livelihoods of rural and marginalised groups, etc.

BOX 6: COMPARING SEF IN INDIA AND JORDAN – PROJECT DESIGNS AND INSTITUTIONAL AND REGULATORY ISSUES

The Indian experience is different from SEF Azraq in the sense that combined SEF applications focusing on agricultural modernisation are dominant in India, in contrast to the stand-alone SEF idea of SEF Azraq. At the same time, out of the wide range of projects and programmes in different states, the ones presented in this report share some important commonalities with the underlying ideology of SEF Azraq. The first two cases (Gujarat and Karnataka) presents projects where combined SEF is enhanced with attractive PPAs, thus making the sale of surplus power and the substitution of traditional farming with solar farming possible. The highlighted projects, using pay-as-you-go models and water cooperatives to encourage farmers to become solar farmers while addressing issues of irrigation optimisation, at the same time make for illustrative project cases where sectoral change and gradual livelihood transformation is facilitated and supported. Such gradual change allows for accommodation of farmers' realities, while the strong participation of the energy sector is an important lesson for countries such as Jordan. The second two cases (Rajasthan and Odisha) represent cases of SEF applications without a PPA but with a focus on linking solar power use to water harvesting and aquifer recharge. They represent relevant cases for the Azraq basin as the underlying water conservation goals of SEF Azraq as addressed through other means, *i.e.* linking SEF to water issues at large. Although, these projects are different from SEF Azraq since they do not aim at power sale, including a PPA on net-metering base for solar pumps in the future is not excluded. The last case (West Bengal) represent an interesting case where solar pumps are used to offer water as a service for farmers who pay according to the monitored amount of delivered water. This approach can be interesting for small-scale farmers in Jordan who cannot afford solar-powered applications, and can profit using the professional services of intermediaries. In this case, no PPA is included, but the water-reduction goals of SEF are still addressed through smart monitoring.

Apart from the project design, the Indian case provides useful insights into institutional and regulatory issues. First, it is important to address SEF as a part of renewables legislation and policies, but with specific programmes and strong commitment. In India, SPISs are supported through a special programme under the national renewables programme (JNNSM). This ensures funds, commitment, and collaboration of the agricultural sector. Newer projects at state level, and in collaboration with donors, tap into this programme in order to develop SEF projects with a PPA with similar orientation to SEF Azraq, namely reducing water use in agriculture. This means that SEF projects can be institutionally embedded in already-developed programmes, which also reduces coordination issues. Secondly, governmental banks are supervising the subsidisation programmes while, in recent schemes of the programme, so-called "system integrators" buy the SEF applications and provide integrated solutions (system, installations, maintenance) through designated dealers to farmers. In this sense, farmers can choose the dealers, request the subsidised loan, and then receive the SEF solution with few transactions. (See Shim (2017) for an overview of the new process.) This enhances the availability of SEF applications and helps farmers who lack the capacities for understanding SEF applications and maintaining them. Such lessons on strong and mainstreamed governmental support can be valuable for future projects in Jordan.

7

UPDATING SEF PROJECTS IN JORDAN – INSIGHTS AND OPTIONS

7. UPDATING SEF PROJECTS IN JORDAN – INSIGHTS AND OPTIONS

7.1 Technological design options

The diverse experiences of SEF reflect the multiple and, sometimes, conflicting goals attached to SEF projects. For example, easy access to solar energy often promotes inefficient use of water and energy. In addition, net-metering of many small solar pump stations can be more costly than metering water use at agro-wells. Such examples highlight the inherent trade-offs in designing SEF projects, or in fact any WEF nexus project for that matter. This report has already discussed general trade-offs and synergies of SEF depending on the limiting resource potentials such as the availability of water. In this part, the focus is on SEF in water-scarce regions, and in particular the Jordan case. Here, the goal of SEF is mainly to contribute to groundwater conservation through improved income opportunities for farmers using solar power. For this to succeed, the key to minimising trade-offs and increasing synergies lies in optimal project design and implementation. The report has highlighted critical issues as well as the context of implementation in previous parts. In the following parts, it will introduce prospective issues regarding the project design. The design options presented draw on international experiences and are indicative of current directions in project design. They do, however, need to be further analysed in terms of costs vs benefits and their suitability for a concrete endeavour in Jordan or elsewhere.

The advantages in terms of the main positive contributions, as well as the potentially problematic aspects of the technical design options, are listed in Table 3. There are two key aspects regarding the technical design that can affect the costs, the acceptability, or the viability of water-use re-education. Firstly, the level of integration determines whether the SEF project can directly address the concerns of sectors such as water and agriculture. While all suggested SEF projects should offer the pay-back option in order to indirectly reduce water use, some projects specifically incorporate designs to ensure improved water or agricultural practices. Secondly, the level of grid connectedness is a much-debated issue in SEF projects, and should be considered carefully. While the goal is to allow for selling of surplus energy, the optimal level of production and metering of this surplus requires careful deliberations among water, agricultural, and energy stakeholders.

The options presented in Table 3 are briefly defined in the following:

Integration

Integrated project design.

In this case, the projects include some add-ons to address water sustainability issues. No limits are attached to the core SEF technical design. For example, solar water-pumping projects are complemented by measures to instal micro- or drip-irrigation systems. The purchase or installation of such a system can also be a precondition for subsidies on solar energy plants. The core idea is to improve the level of sustainable and productive water use. If there is no monitoring, this can lead to farmers expanding irrigation.

Solar sharing.

This is a specific dual (solar–agricultural) design of the SEF plant itself. (See Part 1.2.) It allows for productive land use for agriculture underneath the solar panels, and is increasingly practiced in countries such as Japan[32]. Although this option can be attractive for farmers in the Arab region, it might maintain the high water-use rate, and in some cases increases it.

Agricultural modernisation.

This is the simpler and more widely used option of providing solar energy in order to improve agricultural productivity. Solar pumps or multi-purpose solar plants are encouraged with the hope that farmers will reduce irrigation water for the sake of selling solar surpluses. Often, if adequate incentives are not attached, cheap energy raises water use.

Connectedness

Mini-grids.

Mini-grids, if connected to the national grid, allow for evacuating the solar surplus at one point, thus saving administrative and connection costs associated with net-metering of all solar pumps and agricultural solar plants. Mini-grids with storage options are suggested for countries such as India where it is de facto impossible to connect all farms and households using solar mega-plants and national grids[33]. IRENA (2015b) reviewed international experiences with mini-grids, citing few off-grid and grid-connected applications in regard to solar pumping with a PPA. In fact, this option might not necessarily be good for small countries such as Jordan, but its costs vs benefits need to be considered in further analyses.

Grid-connected SEF plants.

Selected grid plants can be connected to the grid for power use and production. Location, size, ownership, financing, and operation of these plants need a careful study. For example, too many small plants are cost-intensive. A utility-scale plant might not benefit all farmers. The cost/benefit of this option is site-specific and needs to be worked out with concerned stakeholders, especially farmers and the grid operators. The Indian example shows, however, that this option is viable and implementable even with small-scale plants. The political will and the support from the energy sector is key in this regard.

Net-metering of pumps and farm-level plants.

This option is promoted in the example of the Surya Raitha programme of the state of Karnataka, where net-metering of solar pumps up to 10 kWp is financially supported. Here, net-metering works like the case of roof-top solar power. This option is possible in Jordan on a non-commercial basis. It was excluded from the Azraq SEF project due to the prospect of profitability and the higher proposed plant capacity. However, the economic surplus from net-metering of a residential household or a small solar pump is not that different in terms of being a profit; the difference is only with respect to the nature of the beneficiary (farmer or an urban dweller) and his incentives. In any case, the viability and the need for legal reforms to allow this option in Jordan need further discussion. It still provides the highest level of incentives for farmers.

7.2 Policy and institutional options

Four key aspects can determine the performance of the institutional and policy design in an SEF project, as presented in Table 4. Firstly, the level of subsidisation in terms of financing the investment costs as well as the height of the feed-in tariff influence costs and acceptance. Secondly, the level of regulation of water use determines whether the project achieves its ultimate goal of water-use reduction. Thirdly, the institutional arrangements, if any, for farmers' cooperation can determine farmers' capacities and their acceptance. Fourthly, in order to support farmers, especially in developing counties, in developing knowledge related to SEF, options to encourage this are included. The different options generated by the four categories will be explained in the following.

Subsidisation

High subsidisation.

This is practiced in many parts of India in the case of SPSs. Most investment costs are subsidised, while the high feed-in tariffs represent another form of subsidisation. In theory, this promotes a wide use, especially by marginalised and poor farmers. As explained earlier, this can, however, lead to adverse effects, and even limit dissemination. Sometimes, the electricity supplier might back away from paying for surplus solar power high prices that are sometimes 12–15 times the rate of the heavily subsidised electricity price (Bassi, 2018). Note that sometimes the grid electricity is even supplied for free. However, in Jordan, the day- and night-time grid electricity for agriculture is supplied at between 0.049 and 0.059 JD per kWh (around $0.07 and $0.083[34]). The revised selling price of 0.055 JD/kWh or $0.077 for solar power purchase is thus an improvement for the energy sector. In fact, this new price is similar to price levels some scholars suggest for India, namely between Rs4.5 and 5 ($0.07–0.08)/kWh, or (see Shah et al., 2014). Of course, this competitive price can decrease the incentives to farmers for producing solar power. However, it still makes SEF in the Azraq basin more profitable than farming, according to GIZ studies.

Moderate subsidisation.

This implies a competitive feed-in tariff, in the range of the suggestions discussed above, together with some form of subsidisation for capital costs. In any case, subsidisation should be done on a flat-rate basis. Subsidisation through cheap loans through governmental banks might not be enough to encourage farmers due to the high investment costs. Moderate subsidisation gives a good balance of advantages and disadvantages. The experience from India show that public engagement is needed through guarantees or special loan programmes to increase the access to affordable loans for farmers. Governments might choose to grant some of the fixed costs.

Low subsidisation.

In cases where no subsidisation is offered, it is difficult for the SEF technology to disseminate, considering the high fixed costs. Private banks might be unwilling to give cheap loans to small-scale farmers due to the high risks involved related to their low education, entrepreneurship experience and thus profitability outlook. Eventually, inequalities and monopoly-like structures can develop where farmers with high financial revenues capitalise on opportunities for solar-power production, selling services at higher prices to poor farmers.

Regulation

Pricing reforms.

It is possible to use the metered solar power used at pumps or farm-level solar power production as proxies for water pricing. Metering for pricing purposes can be done using remote sensing and GPRS technologies integrated into the technical design of PV systems. In Jordan, this can help in improving the inefficient and unenforced agricultural water pricing policies. The current pricing policies differentiate between legal and illegal wells, and blocks of water abstraction. For legal wells, there is a free block up to 150,000 cubic metres, while the price for the highest block is around 0.06 JD, or $0.085 per cubic metre. Water from illegal wells is priced much higher, with water from saline wells much less. However, the pricing system is often not enforced, while political influence of farmers has in the past led to price reductions (Al-Naber, 2016). It can thus be doubted whether any price increases will be accepted. Still, metering of solar energy can provide for future opportunity to improve the coverage and enforcement of water pricing by using the new data.

Regulatory command and control.

In theory, there is a range of regulations that can be adopted together with solar power generation and use. This can include caps on operation hours/days of solar pumps, regulations for use purposes (e.g. for irrigation or in joint use with modern irrigation systems), or punishments for expanding irrigation using solar pumps, etc. As in the case with water pricing, regulations can be difficult to enforce.

Monitoring and information.

This approach includes gathering data, e.g. using remote sensing, mobile phones, or installed chips in the pumps, for monitoring and awareness. Farmers can also access data to monitor their performance, eventually leading to better water-use patterns. Furthermore, data can be used for training and capacity-building. This approach does not involve enforcement, and represents low-hanging fruit that should be considered for picking.

Cooperation

Community-based.

Famers can cooperate in user associations, enterprises, or joint liability groups in setting-up SEF projects. Capacities and financial resources are thus pooled, and trust is enhanced. Another advantage is that such cooperation can enhance honesty through peer monitoring. The challenge here is how to set up a homogenous group of farmers (a community) that can exhibit all the good elements of this approach. In the Azraq basin for example, large and influential farmers are increasingly dominating the production. The approach can thus be considered for small and medium-sized farms in the area or elsewhere.

Water as a service.

Here, solar power is provided and sold through a pay-as-you-go model. The plant owner can be a professional public, private or non-profit enterprise. Farmers save efforts and costs while they consume water services from a well-maintained network. Surplus power is sold back to the grid. This model works elsewhere, and can be considered for some parts of Jordan.

Individual ownership.

This is the most basic form, where individual farmers carry costs and risks. These farmers sell power provided through net-metering or a small SEF plant. In this case, capacity-building support, subsidisation, and continuous monitoring of the performance and commitments of farmers is essential.

Support

Public services.

Under this option, public services such as extension services for farmers offer advice on PV installation, maintenance, and the needs of the competitive sector renewables. Extension services can, however, deliver such services only to a limited extent since they lack the knowledge on energy issues. It is therefore advisable to embed these services in national programmes on SEF. For example, in India measures to increase capacity building (e.g. hotlines, training initiatives) are funded by the SEF programme. However, there are still not enough capacity-building measures in place, and this role is often performed by public foundations (e.g. the Sehgal Foundation) or donor projects (GIZ, 2013).

Private intermediaries.

Private companies can act as important intermediaries in supporting farmers using SEF applications. In India for example, private intermediaries consult farmers on the use and purchase of SPISs. In developed countries such as Germany, private intermediaries support farmers in installing PV plants and profiting from high FITs. However, these private intermediaries for the support of farmers' transformation into solar farmers represent an organic, market-driven phenomenon which is only possible due to the profitable outlook of the transformation to solar farming in Germany[35], particularly before the new renewables law of 2017 in which the guaranteed, fixed and high FIT was changed in favour of a more flexible one. It is therefore difficult to replicate the experience of private intermediaries from Germany or other developed countries in developing counties with no PPA for SEF.

Category	System design	Main contributions	Potential problem areas
Level of integration	Integrated project design, *e.g.* solar pumping with drip irrigation or/and water harvesting	Increase in water-use efficiency Possible decrease in water use Increased aquifer recharge	Difficulty in controlling the implementation Possible decrease in irrigation area
	Dual solar–agri-cultural systems (solar sharing)	Maintaining productive agricultural use of land Potential reduction of irrigation needs due to higher soil moisture underneath the panels	Site-specificity of feasibility and optimal design No water reductions or potentially higher water use
	Agricultural modernisation	Improved access for irrigation water Improved land productivity	Possible water-use increases Missing incentives for water-use efficiency
Grid connec-tedness	Mini-grid	Lower connection and ope-ration costs than connecting smaller plants or the pumps Flexibility in design in relation to national grid and local supply Possible separation of irrigation solar power supplies from residential ones	Potentially unsuitable for small countries and in the availability of national grid Not optimal if net-metering of all sub-systems is required Little control over individual solar production if the produced power is evacuated to one single point
	Grid-connected selected SEF plants	Connection and operation costs less than net-metering Better control at the level of plants Possibly less costly than mini-grids	Plants needs to be large enough to justify the connection costs Operation and ownership of plants needs to be clarified
	Net-metering of pumps and plants at farm level	Individual control over solar production and consumption Higher incentives for water and energy saving	High grid connection and operation costs High costs for ensuring grid stability and power quality

Table 3: Technical design options for SEF projects

Category	System design	Main contributions	Potential problem areas
Level of subsidisation/ public engagement	High subsidisation	Higher acceptance by farmers Higher access, and possibly equity, in solar power development	Adverse incentives such as the purchase oversized, water-wasteful systems Negative on technology dissemination In case of a high FIT, possible malpractices such as meter-tampering Cost-intensive, while subsidies might favour large farmers
	Moderate subsidisation	Optimal balance in terms of promoting acceptance, access, and technology dissemination Cost savings	Small farmers might still not be able to afford the purchase of the SEF systems
	No subsidisation	Increase of economic competition No costs	Little acceptance or affordability by farmers to adopt solar power Possibly promoting inequities within farmers, since large farmers can better afford solar energy
Level of regulation of water use	Pricing Reforms	Pricing water based on solar energy use promotes savings Simple to administer and effective	Politically difficult to adopt due to low acceptability Requires effective metering and enforcement
	Regulatory command and control	Low administration cost in compliant cases Easy to adopt	Requires punishments, monitoring instruments and enforcement mechanisms
	Monitoring and information based	Provide simple incentives for voluntary compliance Possible improvements on water-use efficiency	Less effective than economic and regulatory instruments Might require high costs for installing the monitoring systems
Level of cooperation among farmers	Community-based	Pooling capacities, improving honesty and peer control Dissemination of economic benefits	Capture by strong or influential members Difficulty to find homogenous groups or communities
	Water as a service	Improving solar plants' operations and profitability as well as irrigation practices No running costs for the farmers	Forgone benefits for the farmers from not being owners Might mean a water price increase, leading to unacceptability of farmers
	Individual ownership	Provide most incentives for farmers	Difficult to monitor and enforce in case of malpractice
Support for capacity building	Public services	Provide publicly funded capacity building services	Require significant public funding and also engagement from civil society and other donors
	Private intermediaries	Offer integrated private services for SEF and transition to SEF	Do not emerge if there is no attractive PPA for SEF, since farmers cannot pay for the services later on

Table 4: Policy design options for SEF projects

7.3 Integrated analysis and optimal set-ups

The optimal set-up of a SEF project is dependent on a thorough analysis of different advantages and disadvantages of technical and non-technical design options in order to achieve certain objectives. Table 5 provides an example of such an integrated analysis. Here, the evaluation criteria represent the typical goals of a project such as the Azraq SEF. The focus is on reducing groundwater usage through SEF. A higher weight can thus be attributed to this goal. Costs for setting up the SEF plant, grid connection and cooperation, or for add-on measures such as improved irrigation systems, water harvesting or capacity building, need to be reduced. At the same time, increasing farmers' incomes and increasing acceptability among farmers and policymakers of SEF as a sustainable livelihood are equally important. Note that the category "support" is not included, since the support of farmers to develop adequate capacities is an overarching topic that does not relate directly to the evaluation criteria.

Evauation Criteria	Options: --- very negative correlation +++ very high positive correlation				
Integrated project design, *e.g.* solar pumping with drip irrigation or/and water harvesting	-	---	---	+++	++
Dual solar–agricultural systems (solar sharing)	+++	+	-	+++	+
Agricultural modernisation	++	+++	+++	++	+
Increasing socio-political feasibility	++	+	+	-	++
	Integration	Connectedness	Subsidisation	Regulation	Cooperation

Table 5: Evaluation of design options using the SEF Azraq example

Table 5 shows, based on international experiences and the detailed Azraq case analysis, how categories of design options correlate with the SEF objective. Firstly, a high level of integration between SEF and measures to reduce water abstraction will be favourable for groundwater abstractions, farmers' income (*e.g.* better irrigation and thus land productivity) and acceptability (*e.g.* of water-sector institutions and farmers alike). However, the add-on measures require additional cost. Secondly, increasing the connectedness in project design through expanding grid connection or net-metering of pumps and SEF plants entails high costs. It is, however, beneficial for farmers, and, in the presence of favourable incentives, reduces groundwater use. The acceptance by farmers is probably high due to addition income opportunities. However, energy stakeholders might not accept a high level of connectedness.

Thirdly, a high level of subsidisation can increase farmers' income and acceptance, but it is costly, politically controversial, and might have adverse effects on groundwater. Fourthly, regulation, if enforced, is highly favourable, although it might incite resistance from farmers. Fifthly, the impacts of increased cooperation among farmers in setting up SEF projects depend on the concrete organisational set-up. If carefully designed, it brings out commitments for water use, saves costs (*e.g.* less monitoring and connection costs), spreads income opportunities, and motivates farmers.

BOX 7: WHICH FUTURE SEF SET-UP IS SUGGESTED FOR JORDAN?

The provided overview of advantages and disadvantages of different design options (Part 7.2) as well as the provided example of assessing costs and benefits (Part 7.3) illustrate that designing an SEF project is a complex, multi-criterion problem. Ultimately, the design set-up should be done in a participatory way and by studying the case context (Part 9). However, one can discuss different design options here considering the *status quo* of SEF-related policies and the SEF Azraq experience. In fact, the critical contextual points in the current SEF application are those related to the PPA and the fixed-cost subsidisation, since other issues (linkages to other sectors, participation modes, *etc.*) can be addressed by the project design. (See Part 5.3 for the summary of critical factors.) With regard to these two issues of the PPA and subsidisation, the current renewables energy law does not seem able to address them. On the one hand, the net-metering and the wheeling regulations are not oriented towards profits. Allowing profits from net-metered or off-site PV installations and offering attractive high, fixed FITs can generate a rush for solar farming which can lead to pricing and capacity problems. Other countries such as Germany adopted this approach in order to stimulate the renewables market. In Germany, farmers switched to solar farming, making profits while consumer energy prices went up. Recently, the FIT has been changed to being on tender basis, and could reverse some farming decisions in the future. In the context of the competitive large-scale projects under way in Jordan, Jordan is unlikely to make general exceptions for wide-scale, profit-oriented net-metering in agriculture. At the same time, exceptional exemptions under the unsolicited proposals scheme proved difficult in the past, and it is difficult to conceive how the exemption procedure can be the way forward in upscaling SEF in other projects. Of course, farmers can invest and compete in commercial large-scale farming; however, the success in this regard is limited to a small number of farmers. Instead, for solar energy to contribute to social development objectives in the water and agricultural sectors there is a need for a special programme that offers similar incentives as the presented cases from India, namely some subsidisation and a special FIT.

The SEF Azraq project sought to negotiate these advantages for the pilot project, but, in the absence of a designated programme, it was difficult to justify exemptions or show the up-scalability of the project. On the project design level, the focus on making farmers compete as solar farmers is difficult to justify as a rationale for special programmes. There is no guarantee that, if subsidisation is phased out, farmers can continue to be competitive, or that farmers will abandon agriculture or use less water. Instead, welfare contributions other than employment opportunities of farmers should drive special funds for SEF, such as improving water-use efficiency in agriculture or reducing the high water-footprint of the sector as an overarching challenge for Jordan. In order to make these crucial links, a certain level of integration among water, energy and agricultural issues and regulation of farmer's practices in needed. Here, a SEF programme can build on the valuable experiences that support communities in managing and/or owning SEF endeavours. This level of cooperation can improve peer regulation, achieve a moderate level of connectedness (for larger systems), and offer opportunities to work with the private sector. In optimal cases, irrigation or energy services can be provided to the served community, with excess power sold to the grid. At the same time, the regulation of subsidisation can be used to select adequate communities that allow monitoring and provide commitment on societal objectives such as recharge activities, irrigation practices, and cropping. The design of such suggested SEF programmes with funding commitments and community-level arrangements is, however, a challenging endeavour and should be seen here as an approach for further analysis in terms of merits, contents, criteria, locations, *etc.*

In summary, a key insight from such an integrated analysis is the need for finding the right balance of these design categories. In the Azraq case, an increase in regulation and integration seem to be the most favourable design policies. Subsidisation and connectedness need to be designed carefully and moderately. Furthermore, cooperation among farmers is generally desirable, but needs a careful preparation and set-up in order to minimise problems such as resource capture.

8

COMPARATIVE INSIGHTS FROM JORDAN AND THE ARAB REGION

8. COMPARATIVE INSIGHTS FROM JORDAN AND THE ARAB REGION

Comparative analyses in this report can provide some useful and broad insights and recommendations for the SEF projects in the context of Jordan and the Arab region at large. The presented insights are little determined by specific sociopolitical contexts, although such contexts also need to be considered, as will be explained later. The key insights are presented in the following section:

1. Public commitment.

SEF involves many critical public policy decisions on the nature of renewables, infrastructure, the future of farming systems, or the state of vulnerable water resources. It provides an opportunity to establish policies that can address all these issues in an integrated manner. For this, a clear public commitment for such an integrated approach is necessary. In the Indian case, there was an early commitment with significant investments in renewables promotion and solar pumping for improving agricultural livelihoods. Although this governmental engagement is criticised for contributing to increased water abstraction due to cheap energy promotion, the government seems to be still engaged and open towards newer projects and policies using more integrated and smart approaches. This might not reverse the trend on groundwater abstractions, at least not immediately. However, it shows that large public investments for SEF and power surplus purchase from farmers, as well as the promotion of smart irrigation, are being committed. In contrast, Jordan's experience with renewables in general and SEF in particular is still evolving. For SEF to be a success in Jordan, it requires a stronger public commitment in financing, providing support for improving capacities, and also exploring small-scale SEF with a PPA that can achieve important social developmental goals such as decreasing water overexploitation.

2. Stakeholder participation.

The nature of SEF projects requires a strong modus of participation, especially by the agricultural and energy sectors. In the Indian case, both sectors are highly engaged. In fact, SEF is under the leadership of the energy sector. This is not the case in Jordan, where the water sector is promoting the idea, and the ownership of the idea among the energy and agricultural sectors is largely missing. At the same time, these actors are key for SEF success. Energy sector leadership is of utmost important for realising the technical implementation of SEF. Moreover, agricultural institutions such as banks, extension services or civil societal services are key to improving capacities of farmers and providing aid. They act as a key link and a mediating force between the water and energy interests.

3. The need for smart and integrated designs.

Many examples have been highlighted in this report of innovative project approaches that either integrate SEF into water-saving measures, or provide smart technologies and subsidies. These projects exist worldwide, and are growing in size in the light of evidence on adverse impacts of subsidising one-sided solar power projects. The potential for mutual learning and experience exchange on these projects is high. For example, there is a benefit in learning not to repeat the same errors. At the same time, when upscaling project experiences elsewhere, innovative aspects of other projects can be used as design options. As *this report highlighted earlier, the different design options must be analysed and weighted towards achieving the context-specific objectives of each project. The design process of integrated and smart SEF project needs to be done properly and context-specifically.*

4. Incorporating farmers' realities.

The success of the overall strategy of reducing water abstraction through the provision of an alternative livelihood depends on the decisions and choices of farmers. In order to facilitate this success, the farmers' realities need to be analysed adequately. This reality influences the feasibility as well as the optimal project design. It includes technical (e.g. quality and sources of the used water, soil conditions, water-use technology, cropping and growing patterns, climatic issues), economic (e.g. prices, markets, revenues), and social issues (e.g. non-use values of land, land ownership patterns, trust in technology, etc.). A single factor can affect a farmers' decision to abandon, increase or decrease agricultural land use for SEF. For example, in India many SPSs and SEF projects are oriented towards small, poor and marginalised farmers suffering from climate variability and low land productivity. The acceptance of the support of SEF projects seems to increase under these conditions. In the Azraq case, in contrast, professional, large-scale, and sometimes, privileged farmers are prevalent. There is a need to incorporate these realities in project designs. Table 6 provides some further examples of farmers' realities in different socioeconomic contexts.

5. SEF capacities.

The number of SEF projects and experiences, and the sheer scale of supported farmers have helped to develop some capacities for administrating these projects (e.g. integration of policies and stakeholders) and providing support to farmers. Nonetheless, capacities building, especially for farmers and extension services or other intermediaries working with farmers, is highly needed in the Indian context (see GIZ, 2013). This is even more important in the Jordanian context given the novelty of the SEF idea.

Industrial Countries	Farming businesses are highly professional and driven by profits. Cost-optimisation on a regular basis Farming is often lucrative. Farm arrangements (size, ownership, organization, *etc.*) are determined by profitability. Clear land rights, thus easy to sell and rent. High mobility and affluence of farmers, thus easier to adapt to new jobs and technologies. Favourable geography means abundancy of fertile land, thus lower value of land.
Arab World	Farming is a craft inherited through generations. Professionalism and farmers' education are generally lower. For many farmers, agriculture is for subsistence purposes and meeting basic needs. Land rights are not clear, thus difficult to decide or change land use purpose. Scarcity of arable land means a high personal value attached to land and agriculture. High social valuation of being a farmer; land is considered equal to personal pride/honour. Low mobility of land owners, and thus lack of capacity to change. Sometimes elites (*e.g.* tribal actors or high-level officials) hold-land for mainly recreational/retirement purposes

Table 6: Examples of social and financial reality of farmers

9

GUIDELINES AND RECOMMENDATIONS

9. GUIDELINES AND RECOMMENDATIONS

SEF projects are complex and pose many challenges in the conception and integration. This chapter explores ways to systematically address some of these challenges. Figure 8 depicts a proposed cycle for the conception (preparation and development) and implementation of SEF projects. The cycle serves as a systematisation of the SEF approach in order to cover as many as possible of the key success factors mentioned previously. The cycle consists of six key steps (determination of objective function, case study analysis, project design, piloting, project promotion, and upscaling of experiences) and two accompanying processes (stakeholder involvement and capacity building). The first three steps summarize the conception phase of ahead of project implementation. The policy objectives from a SEF projects need to be determined. As explained previously, the motivation behind SEF projects is diverse and can include solar energy access, increased agricultural productivity, targeting poverty, decreasing water use *etc.* Different objectives can be addressed by a single project, and there needs to be a prioritisation of objectives based on broad planning principles. Defining the relations, weighting or any constraints or condition among the objectives can help in deciding on the project design options. For example, if unavailability of subsidies is a strict constraint to the goals, community-based management of SEF can be favoured over individual ownership even though the latter is a better option for improving farmers' income.

In addition, the objective function must be based and an in-depth analysis of the specific conditions in the project location. Such analysis can revise the objective functions in case some objectives or conditions are determined as not realistic or feasible for a particular case. This iterative process can help exclude factors that can lead to project failures later on. The location or case study analysis should include the analysis of the resource use problems, involved actors, their interactions, and the impacts resource use. For example, considering farmers' production realities and power asymmetries involved help understand important aspects such as organisational and technical capacities. The project design options follow the pattern highlighted in the previous chapter. Evaluation criteria are developed in order to reflect the objective function. Later, options are generated and evaluated based on the evaluation criteria in order to select the optimal design. With this, the iterative conception phase is completed.

In phase of implementation, it is wise to run a test through piloting an innovative project design to the new case. The results and evaluations from this pilot project is to be promoted in preparation for upscaling the project by expanding it or applying it elsewhere. The key for the success of the implementation is cooperation of all relevant stakeholders and the availability of adequate institutional and technical capacities. In order to facilitate these factors, they should be incorporated in the processes of the conception phase. Broad stakeholder involvement starts with defining the objectives and analysing the case. The stakeholders need then to accompany the project through the design phase where they receive capacity building measures on technical aspects of the projects such as available technologies for SEF, international experiences, possible institutional arrangements *etc.* Capacity building continues through the project implementation until the first success is achieved. Later, stakeholders are again involved in defining and developing new projects.

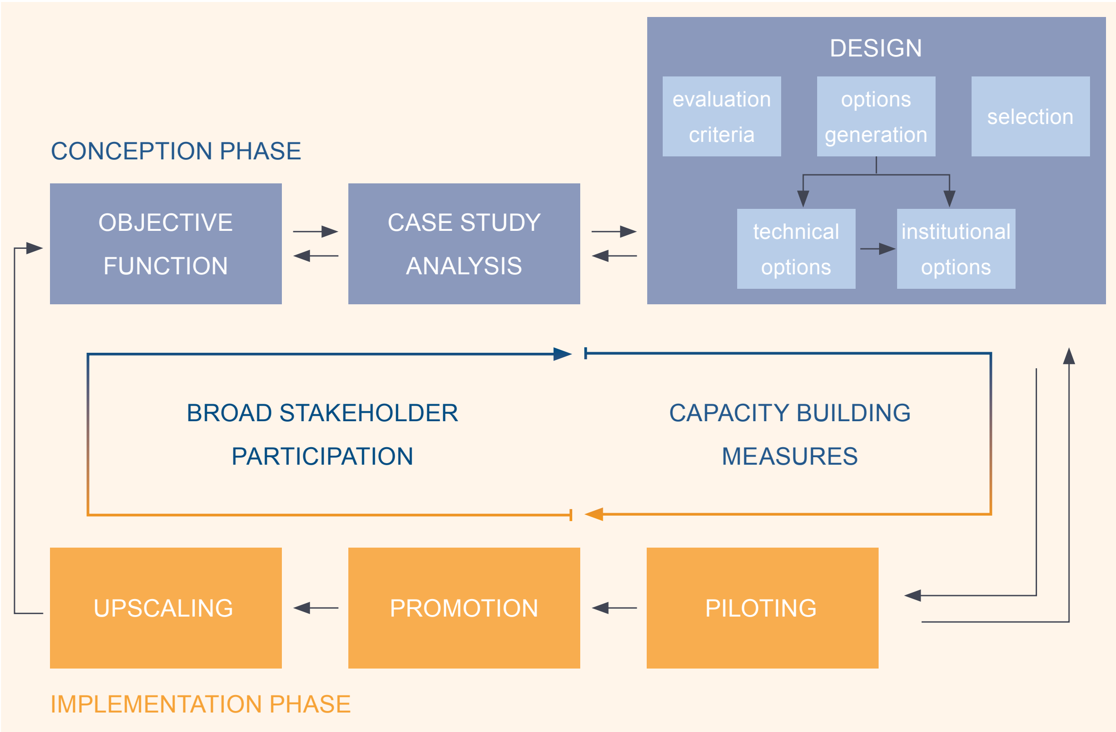


Fig. 8: Cycle for SEF conception and implementation

9.1 Concluding Recommendations

Concluding recommendations for SEF projects in general

1. Assess impacts of SEF programmes using an integrated water–energy–food nexus perspective that considers resource potentials and current use patterns.

Such an integrated lens helps in understanding the synergies and trade-offs involved with SEF in a particular case. These synergies and trade-offs should be estimated in order to address them through a smart project design.

2. Use a systematic approach in designing SEF projects

in order to incorporate the time needed for understanding the project's environment, the design options, testing the interventions on a small scale, and involving stakeholders as well as building capacities. A systematic approach to design helps to keep track of the project's progress and identify missing elements.

3. Consider total economic and welfare aspects alongside financial aspects.

The financial investments in SEF project are exceeded by savings in fuel subsidies and the economic value of the reduced amount of water because of improved efficiency or reduced total use. In addition, SEF can have other social benefits. The estimation of all of these benefits is important in order to convince policymakers, investors, and farmers. Financial and economic cost–benefit analyses of different available interventions can help make the right choices with regard to the project objectives.

4. Use more integrated and smart project designs.

This requires linking the promotion of solar energy for agriculture to measures on irrigation efficiency and water savings. Smart technological and regulatory designs can improve the monitoring of water and energy use, or raise the targeting of the offered subsidisation.

5. Achieve the right balance between technical and institutional solutions.

Technical solutions determine the opportunities provided by SEF projects. Institutional solutions determine the acceptance and cooperation of farmers, and their access to the provided opportunities.

6. Design the subsidisation scheme carefully in order to minimise adverse effect.

Subsidisation through financial support covering the investment costs or through a special feed-in tariff should not be too high since it hinders competition and incites malpractice. At the same time, it should not be too low as this discourages use and dissemination.

7. Understand the realities of farmers.

Farmers optimise a wide range of variables in their land-use decisions. Land and farming also has many other non-economic values, while land use and ownership are constrained by legal, economic, and cultural aspects. SEF incentives are not important for some, while highly welcomed by others. The study of socioeconomic and cultural realities of targeted farmers can determine the viability of SEF for balancing different water–energy–land goals.

Concluding recommendations for SEF in Jordan

1. Promote energy sector participation in leadership of projects.

Energy sector institutions are leading the way in SEF projects in many countries. Their engagement determines the viability of many of the technical and regulatory aspects of SEF projects. In integrated SEF projects targeting water reductions, energy stakeholders need to appreciate the importance of this approach, and optimally join in as project owners and leaders alongside the water sector institutions. Other cases show that promoting SEF requires special programmes that are often developed with leadership from the energy sector, and embedded in national renewables policies.

2. Empower institutions from the agricultural sector and offer incentives for support and participation.

SEF projects need not to push the idea of substitution of agriculture with solar farming. SEF projects only focusing on a substitution of traditional farming can be criticised for negatively impacting food security and not providing long-term sustainable livelihoods for farmers. Instead, such projects can stress the mutual benefits for the water–energy–food sectors in terms of increase in renewables, water-use reductions, and agricultural modernisation. Agricultural institutions are needed to help convince farmers, ensure quality of the selection process, and build capacities. It is important to convince them of the merits of SEF projects in increasing the choices of farmers as well as their resilience and affluence in a rapidly changing agricultural sector under threat of water scarcity.

3. *Develop convincing strategies using collaboration with key actors and mediating institutions.*

    Close collaboration with stakeholders from the environmental sector (e.g. ministries, NGOs) is important since they act as mediating forces between different interests. They can also contribute to developing convincing arguments embedded in larger developmental contexts.

4. *Provide studies on the technical as well as the institutional and economic feasibility of SEF projects.*

    Alongside the technical (financial and technological) feasibility of SEF projects, institutional issues such as the participation arrangements of farmers, the regulatory context, and the current land use and ownership dynamics require careful analysis. Further, economic cost–benefit analyses considering welfare aspects, marginal costs of water and energy, subsidy savings, and the value of restored ecosystems can help promote SEF projects.

5. *Establish a clear coordination mechanism among public institutions for facilitating decision-making on SEF programmes or projects.*

    The availability of an ad hoc or a permanent arrangement for coordination among water, energy, and agricultural public institutions as well as clear rules for decision-making are important for the success of cross-sectoral projects such as SEF. Such mechanisms need to be elaborated on and documented before negotiating projects designs and required investments.

6. *Offer subsidisation and support for SEF projects through special programmes.*

    Without some form of subsidies such as flat-rate contribution to fixed costs, the dissemination of SEF projects, especially if small-scale farmers are participating, will be difficult. Community-level organisation of farmers can provide cost-sharing alternatives. Special programmes embedded in the renewables policies offer an important opportunity to initiate SEF projects. International experiences show that these farmer-oriented programmes as a part of renewables strategies, if designed with the right conditions and regulations, can achieve important societal objectives such as sustainability in agriculture and reducing water-abstractions.

7. *Explain SEF to farmers first, and then work with them on capacity-building programmes.*

    For farmers to become energy producers and make sound choices between irrigation and power production, they need to appreciate and internalise the idea, the competition involved, and the required capacities. In addition, farmers need to appreciate the advantages of solar energy and its productive on-farm uses.

8. *Explore options for risk mitigation through cooperation of farmers.*

    Organisation and cooperation of farmers in setting up certain SEF projects can, if based on clear rules, enable pooling of financial and technical capacities and thus helping to address failure risks.

9. Incorporate regulations and conditions targeting irrigation and water use in exchange for the support of farmers.

For SEF to be more effective in reducing water use, direct links to water use should be established. There are several options to achieve this through arrangements for better monitoring of water use, improved irrigation practices, or regulations restricting land use to certain purposes or crops.

10. Work with large-scale farmers or farmer communities in exploring win–win SEF projects, especially in vulnerable basins.

Large-scale farmers are often the largest water users, more profit-oriented, and politically influential. In order to significantly curb water abstraction through SEF, their participation is important through mutually negotiated projects that can be on a larger scale and include clear commitments from those farmers for restricting alternative land use for water-intensive purposes. Farmer communities offer similar advantages and can achieve a better distribution of SEF benefits, and an increase in regulation through peer monitoring.

11. Improve competitiveness in the allocation of subsidies and financial support for SEF projects.

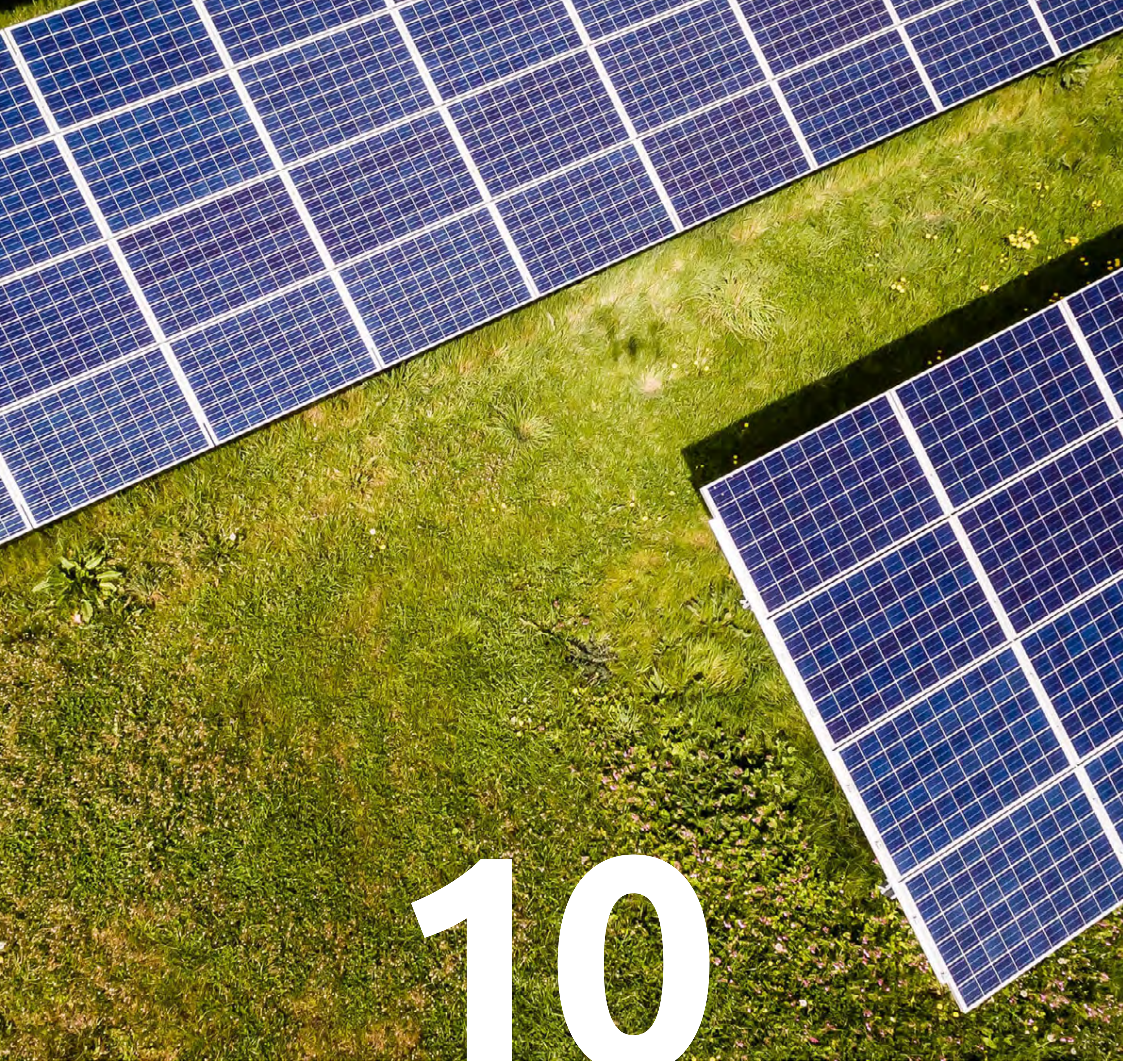
Farmers and investors can compete for the support of integrated SEF projects. There is a need to offer convincing commitments and propose best locations for implementation.

12. Disseminate the knowledge and experience gained from SEF Azraq.

The Azraq SEF project allowed a valuable first look at the viability of the SEF in Jordan and the MENA region. It can be considered for redesign and implementation elsewhere, especially in hydrologically and socioeconomically more stable areas.

13. Promote international experiences and state-of-the-art knowledge on SEF.

The vast international experiences of SEF in regions such as India, some Arab countries, and even Africa, show the growing interest in linking SEF with water-sector objectives. Promoting best practices from selected international cases helps to create an impetus for developing the right SEF programmes and regulations in Jordan and beyond.



10

KEY LESSONS LEARNT

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The report aimed to provide insights that can advance SEF in Jordan and the Arab region by analysing the experience from SEF Azraq, international experiences, and the overall relevance and challenges of SEF from a water–energy–food nexus perspective. The SEF Azraq project concluded in late 2015 and has since not been updated with insights from recent SEF projects, developments in renewables markets, and knowledge on nexus integration. It is therefore helpful to look back at recommendations made for SEF Azraq in 2015 in order to understand the implementation outlook and the need for updates. The 2015 recommendations for long-term implementation included strengthening stakeholder cooperation (water–energy), testing farmers' willingness to engage in SEF projects, developing PPA templates, pre-screenings of contractors, eligibility criteria for financial support, conducting further technical assessment on the grid, and continuing to engage with farmers (GIZ, 2013).

Since the project did not advance due to lack of agreements (*e.g.* PPA schemes) and participation (*e.g.* the energy sector), further technical steps in line with these recommendations were not taken. It is unlikely that these recommendations can help advance the project today. Instead, much has changed that indicates that the original project idea should evolve as well. In fact, the reduction of the baseline FIT by almost half in 2016 reduced the profitability outlooks considerably, although the project was still judged to be feasible (*i.e.* more profitable than traditional farming) by an update to the technical feasibility study. Since that time, the renewables energy market in Jordan has become quite competitive. Furthermore, the cross-sectoral coordination issue was not solved. A recent nexus assessment for Jordan shows the need for such coordination, and options to achieve it through existing or new mechanisms (*e.g.* a nexus committee or a council) (GIZ, 2017). At the same time, international experiences on SEF provide important insights that make updating knowledge about SEF Azraq important. Firstly, SEF experiences in developed countries show that the transition of traditional farmers to solar farmers is a complex decision that often happens voluntarily and with no designated projects or programmes, *e.g.* in response to higher profits provided by renewable policies with attractive FITs in order to stimulate renewables transitions. Secondly, this decision is encouraged by market and sectoral change dynamics. For example, farmers confronted with decreasing profit margins or increasing energy costs adopt solar applications for on-farm use, and might decide to sell all or part of produced power for certain periods. Not all farmers engage in solar farming due to entrepreneurship risks and lack of knowledge. However, in cases of solar farming markets becoming very attractive, farmers can pay for the services of intermediaries to acquire the technology and knowledge for them. Thirdly, farmers' decisions are reversible due, for example, to FIT fluctuations, while the commitment to abandon farming is rarely for the long run. Fourthly, SEF experiences from developing countries such as India that are dominated by

SPIS and solar pumping are increasingly offering the option of purchase of surplus power. New large-scale programmes that aim at balancing farmers' energy needs and encouraging energy savings, which in turn lead to water savings through less pumping, often promote these technologies with a PPA. Fifthly, recent development projects on SEF embed themselves into these power purchase programmes for farmers, and seek to improve farmers' organisation and capacity to utilise the programmes. Here the goal is not to make farmers become solar farmers, but to educate farmers on the use of PPA to generate additional income while optimally using SPISs. In cases where PPAs are not available, projects try to link solar energy use to water savings through the integration of aquifer recharge and smart water metering into funding schemes for SPISs or pumps.

In light of these developments and insights, updated knowledge about the challenges of replacing agricultural activities and transforming farmers' livelihoods is sorely needed. Furthermore, we are starting to appreciate the complexity of cross-sectoral stakeholder collaboration as well as the required instruments. It will therefore take time to be able to implement coordination mechanisms required for collaboration among sectors beyond the entrenched power asymmetries and sector-driven interests that hinder SEF projects. At the same time, the development of capacities of farmers to appreciate the various on-farm and off-farm solar applications is a long-term process. Meanwhile, there are some lessons that can advance the implementation of SEF ideas in the short- or mid-term. Firstly, the idea of SEF Azraq of farming substitution through SEF was quite ambitious as it addressed a long-term process that can hardly happen without larger economic and policy drivers. Besides, abandoning agriculture involved many uncalculated risks for farmers, and similarly, allowing or financially supporting farmers in the competitive energy markets involved many risks for the energy sector.

The stand-alone idea of SEF Azraq did not provide any secondary linkages (*e.g.* to sustainable agricultural or water-use practices) that can compensate for these risks or provide additional benefits. Secondly, there is a shift towards innovative "integrated" projects that link SEF with a PPA to water use, harvesting or reuse practices as well as "smart" monitoring technologies for abstractions or smart subsidisation programmes, *e.g.* competitions or fixed subsidies (not pro rata). This shift provides an opportunity for reviewing the design of future SEF projects and incorporating innovative ideas in cooperation with stakeholders. Thirdly, a balance between technical and non-technical design issues in SEF projects is needed. This means considering not only the feasibility issues related to the grid and plant issues, but also the required level of subsidisation, the arrangements for regulation, the organisation of farmers, and the necessary support. In this regard, community-based approaches that reorganise farmers as energy cooperatives or enterprises providing solar energy, irrigation services, and water-use monitoring are quite interesting to explore. They can achieve a higher level of integration by bundling the required financial and land resources and, if the institutional and social organisation of the "community" is positive, contribute to better regulation and monitoring. In comparison, small farmers might not always have resources (*e.g.* land rights, capacity) to engage in SEF. Besides, large farmers have been shown to be less interested in SEF if they are profiting from the status-quo in terms of favoured treatments regarding land rights and subsidised energy of water prices. Finally, balanced participation of several stakeholders is needed for a successful SEF project and for the development of coordination mechanisms. This means that project owners, leaders, target groups and other stakeholders are involved according to their relevance in making SEF projects happen. In this sense, if SEF projects should incite agricultural farmers to become energy farmers, the projects will have little success when neither the agricultural nor the energy sector is in favour of this. For the water sector stakeholders, it is recommended that they seek equal partnerships. Basin stakeholder groups, civil society, or donors can be initiators of SEF projects, but their efforts need to be clearly embedded and linked to overarching programmes originating in the energy sector. The energy sector has been the leader of SEF-related programmes in many cases, and its engagement is essential for success. Moreover, convincing strategies for the participation of agricultural or environmental stakeholders are needed. Linking SEF projects during the design process to the concerns of these stakeholders can help. Finally, the philosophy of SEF is to contribute to synergies between water, energy, and agriculture. It requires an underpinning with public and growth policies, which should encourage this direction and acknowledge the social and sustainability contributions. On this premise, and as international cases show, a public commitment and development of programmes are essential for the advancement of SEF.

11

SUMMARY

11. SUMMARY

Agricultural water use has increased greatly over the last decades, globally well as in the most arid and hot environments. Reducing water use in the oversized and inefficient agricultural sectors in the Arab world represents a valuable societal project for ensuring a sustainable future. Promoting renewable energies is another such crucial project that will help in saving money, promoting low-carbon lifestyles, and developing clean production systems. These two projects can be linked in innovations such as SEF in order to create exemplary water–energy–food nexus synergies. SEF projects and public programmes exist worldwide, each presenting unique integration challenges. However, they are rarely motivated by water-sector concerns. A majority of SEF projects are developed as either modes of increasing solar energy or a reaction to the impacts of its dissemination. Solar energy is promoted in agriculture-strong countries such as India in order to promote energy and water access and improve the livelihoods of poor farmers. SEF in industrialised countries such as the USA, Canada or Japan focus on joint use of land for energy and agriculture. With solar energy becoming cheaper and more accessible, its dissemination starts to effect water use. However, it must not result in increased water use. It can be harnessed towards changing resource-use patterns to better reflect available resource potentials.

Solar energy for water abstraction and other productive on-farm uses is sorely needed for agriculture in the Arab region. It improves farmers' resilience, productivity, and income. However, water poverty is a major constraint for agriculture in the region. Reforming agriculture implies two important measures: reducing water use via improved efficiency, and releasing farmers towards more productive industries. SEF provides an alternative or additional income for farmers as solar farmers. While SEF will not lead to competitive jobs for famers of the required magnitude, it helps to mitigate the impacts of agricultural restructuring. Importantly, it can incentivise farmers to reduce water pumping or rethink irrigation patterns when set as a precondition for access to solar technology.

This report has highlighted insights from many recent SEF endeavours that aim at linking solar farming to water issues in a smart and integrated manner. It recommends the use of a WEF nexus perspective, more integrated approaches, interdisciplinary and cross-sectoral feasibility studies, and smart design of subsidies and technologies. The comparison of the Indian and Jordanian experiences shows commonalities such as the concern about groundwater depletion. At the same time, Jordan's experience with SEF is modest and recent. The example of the Azraq SEF project can be developed to serve as a valuable vision for future integrated and smart SEF initiatives in Jordan and the Arab World. The Indian case provides important lessons about the consequences of failures to address water issues, and the impacts of adverse incentives in projects linking solar energy to agriculture. At the same time, many new innovative designs link solar energy and water use in agriculture in promising public policies and projects. Much can be gained from updating SEF projects while reflecting the needs and contexts in Jordan and the Arab world. Strong public leadership and concrete commitments from public institutions in the energy, agricultural and water sectors are prerequisites for the viability of SEF. The degree of success or failure will depend on the careful design of the projects. This includes a careful study of the intervention case and the technical and non-technical options. It also means involving stakeholders and improving their capacities throughout the preparation and implementation phases of a SEF project.

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