Energy Policy 104 (2017) 33–37

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Solar-based groundwater pumping for irrigation: Sustainability, policies, and limitations

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ARTICLE INFO

Keywords:
Solar technology
Irrigation
Policy
Sustainability
Groundwater

ABSTRACT

The increasing demand for solar-powered irrigation systems in agriculture has spurred a race for projects as it potentially offers a cost-effective and sustainable energy solution to off-grid farmers while helping food production and sustaining livelihoods. As a result, countries such as Morocco and Yemen have been promoting this technology for farmers and national plans with variable finance and subsidy schemes like in India have been put forward. By focusing on the application of solar photovoltaic (PV) pumping systems in groundwater-fed agriculture, this paper highlights the need to further study the impacts, opportunities and limitations of this technology within the Water-Energy-Food (WEF) nexus. It shows how most policies and projects promoting solar-based groundwater pumping for irrigation through subsidies and other incentives overlook the real financial and economic costs of this solution as well as the availability of water resources and the potential negative impacts on the environment caused by groundwater over-abstraction. There is a need to monitor groundwater abstraction, targeting subsidies and improving the knowledge and monitoring of resource use. Failing to address these issues could lead to further groundwater depletion, which could threaten the sustainability of this technology and dependent livelihoods in the future.

1. Introduction

Agriculture remains a major challenge to achieve overall water, energy, and food security. In order to address the need to increase water access for growing populations, produce renewable and clean energy, and feed the planet, solar-based groundwater pumping for irrigation (referred to SGPI) has been put forward as part of a sustainable energy portfolio for both developed and developing countries. The use of solar technology is expanding worldwide and since 2010 the world has seen more solar energy system capacity installed than during the previous four decades (IEA, 2014). In the Middle East and North Africa (MENA) region alone, solar photovoltaic energy production increased with 112% between 2008 and 2011 (REN21, 2013).

As a potentially cost-effective solution capable to provide off-grid electricity with solar radiation, one of the policy aims of SGPI is to increase agricultural productivity by securing access to groundwater resources for farmers. In the absence of reliable electric supply, these systems seek to provide a viable solution for agriculture as they offer operational and maintenance (O & M) advantages, increasingly low investment costs and environmentally positive trade-offs in the form of carbon free generated electricity. The use of this technology would also reduce variable costs (e.g. O & M costs) and the reliance on diesel or electricity, leading to higher profits for farmers. This solution also addresses the interconnected challenges arising from the WEF nexus by providing safe access to water and energy which in turn contributes to improving food production (Fig. 1) (FAO, 2014).

Solar pumping was already used in the 1960s and 1970s (e.g. van Campen et al., 2000; Rosenblum et al., 1978; Smith and Allison, 1978; Ward and Dunford, 1984; World Bank, 1981) but its expansion was limited to a small number of cases due to its high costs (Howes, 1982, 1984). Recently, a new set of circumstances has recently put it back on the map: 1) a general focus on renewable energies and carbon-emission offsets; 2) the need for increasing food security and improving livelihoods; 3) a radical reduction in solar panels prices; 4) the increase in oil prices; 5) new technical and more affordable designs for small-scale irrigation systems. Experiences include the Gulf countries (Doukas et al., 2006; Sahin and Rehman, 2012), Yemen (IFC, 2014; World Bank, 2015), Egypt (Hattingh, 2013; Mahmoud and El Natherb, 2003), and Morocco (IFC, 2014; Lorentz, 2013). Other countries such as Benin (Burney et al., 2010), India (Shah et al., 2014), Bangladesh (World Bank, 2014), and China (Yu et al., 2011) have also been testing

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http://dx.doi.org/10.1016/j.enpol.2017.01.035
Received 12 June 2016; Received in revised form 18 January 2017; Accepted 21 January 2017
0301-4215/

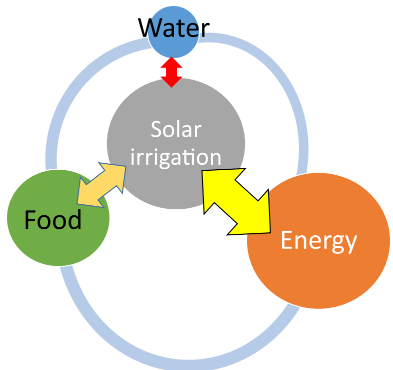

Fig. 1. The water-energy-food nexus and solar-based groundwater pumping for irrigation.

this technology.

Against this backdrop, this paper reviews the application of solar technology with PV for groundwater pumping in irrigation and argues that in most cases where this technology is used, the financial and environmental sustainability of these projects are generally underplayed or sometimes even overlooked. As will be examined, such lack of financial and environmental sustainability can lead to ineffective state policies promoting the technology (e.g. targeted subsidies) and increased groundwater resource overdraft.

Water and energy are both necessary inputs for food production and along the supply chain, with the nexus representing a way to describe the interconnectedness with the existing global resource system (FAO, 2014). SGPI can increase food production by harnessing reliable and sustainable energy to provide timely irrigation. However, these benefits may be at risk as many technical feasibility studies on SGPI fail to appropriately evaluate available water resources and water use (dependent on solar pump extraction capacity) and the arising tradeoffs within the water-energy-food nexus (Fig. 1). For SGPI, variable costs may be lower than other energy options but in the long term total costs (including environmental sustainability of natural resource use and total capital costs) might be considerably larger. The environmental sustainability of SGPI is problematic as assessments generally assume constant groundwater and no varying natural conditions due to increased resource abstraction. Poor regulation, rule enforcement and monitoring of groundwater abstraction levels through state regulation and management may increase the risk of resource depletion from these ventures and their medium to long term sustainability.

In order to further examine these issues, the structure of this paper is as follows: the technological development and limitations of SGPI are scrutinized in the first section. The following section examines the economic and financial limits of SGPI focusing on the impacts of specific state policies such as the use subsidies, access to finance and markets for this technology. The next section addresses the environmental sustainability of SGPI and the lack of assessment and understanding of groundwater resources in most projects. The final section raises some concluding remarks and reflects on potential policy directions to be adopted vis-à-vis the necessity to improve the financial and environmental sustainability of solar-fed groundwater pumping for irrigation.

2. The development of solar-based groundwater pumping for irrigated agriculture

2.1. Solar pumping: a new technological fix

Many developing countries have large energy needs but lack financial resources to expand their electric grid rapidly enough. Aging energy generation plants and increasing population drives the demand for more energy. Solar technology seemingly provides a modular solution for users to quickly develop and independently develop private off-grid electricity-production systems.

Off-grid PV groundwater pumps for irrigation have been studied and used for over 40 years and there is nothing new about the application of this type of technology in agriculture. The technology consists mainly of solar PV panels, an engine and a pump (submersible, surface or floating, according to well characteristics and needs) connected to a well (Kelley et al., 2010; Meah et al., 2009; Van Pelt, 2007). It is only after the 1990s and 2000s that some of the necessary and enabling conditions for developing and upscaling this type of technology have been met, making it more attractive and economical for more farmers worldwide (van Campen et al., 2000). In the MENA region, governments have been encouraging the substitution of diesel pumps with solar-powered ones through credit lines (e.g. Morocco) or by directly investing in such technology in land reclamation projects (e.g. Egypt).

Solar-powered pumps have higher initial costs (the retail price of technology) compared to diesel pumps, but lower O & M costs in the long run, offering higher reliability than diesel generators. Even though capital costs can vary according to each country (for example according to capacity value, stranded costs related to distributed generation, or compliance with environmental regulations), Lazard (2014) established the range of total capital costs for Solar PV between 2500 USD and 3000 USD per kW and for diesel between 500 and 800 USD per kW. However, recent drops in production costs of solar panel technology 30–60% in 10 years, with a historical global drop from around $76/W in 1977 to $0.30/W in 2015), coupled with increasing oil prices have made this type of technology more attractive to decision-makers, technicians, and users (Bloomberg, 2016; Nederstigt and Bom, 2014).

2.2. Technological limitations

A particular set of conditions enhances the technical efficiency of SGPI. Solar radiation and light intensity has to be constant and over a certain threshold. Solar pumps can also be less efficient than diesel pumps as sun radiation variations and exposure can drastically decrease the efficiency of these systems (Ahmad and Ali, 2011). The outputs of solar systems also depend on system design, accurate site and demand data with appropriate measurements. These have to be accurate in order to understand water demand from the irrigation system as well as groundwater availability, something that cannot always be done (for lack of data, studies, or funds to carry them out). Additionally, it has been reported that solar-powered pumps are more suitable for low and medium head water pumping and where grid-connected systems cannot rely on electricity (Gopal et al., 2013), thus making it difficult in some cases to scale up the technology.

The productivity of these systems can be further decreased by the following factors affecting the performance of these systems: ambient temperature, poor maintenance of the panels (dust accumulation and improper cleaning), wind velocity and relative air humidity (ibid.). Solar energy is also not available on demand and cannot cater for fluctuating water demands, unless the daily variation in solar power generation is stored in batteries or lifted water is kept in a storage reservoir, thus requiring further investment capital (Abu-Aligah, 2011). A lack of data makes it difficult, according to Nederstigt and Bom (2014), to estimate pump lifetime and thus annual costs of these systems. No post-implementation studies have been found in order to compare with ex ante feasibility studies and contrast assumptions with results and system performance.