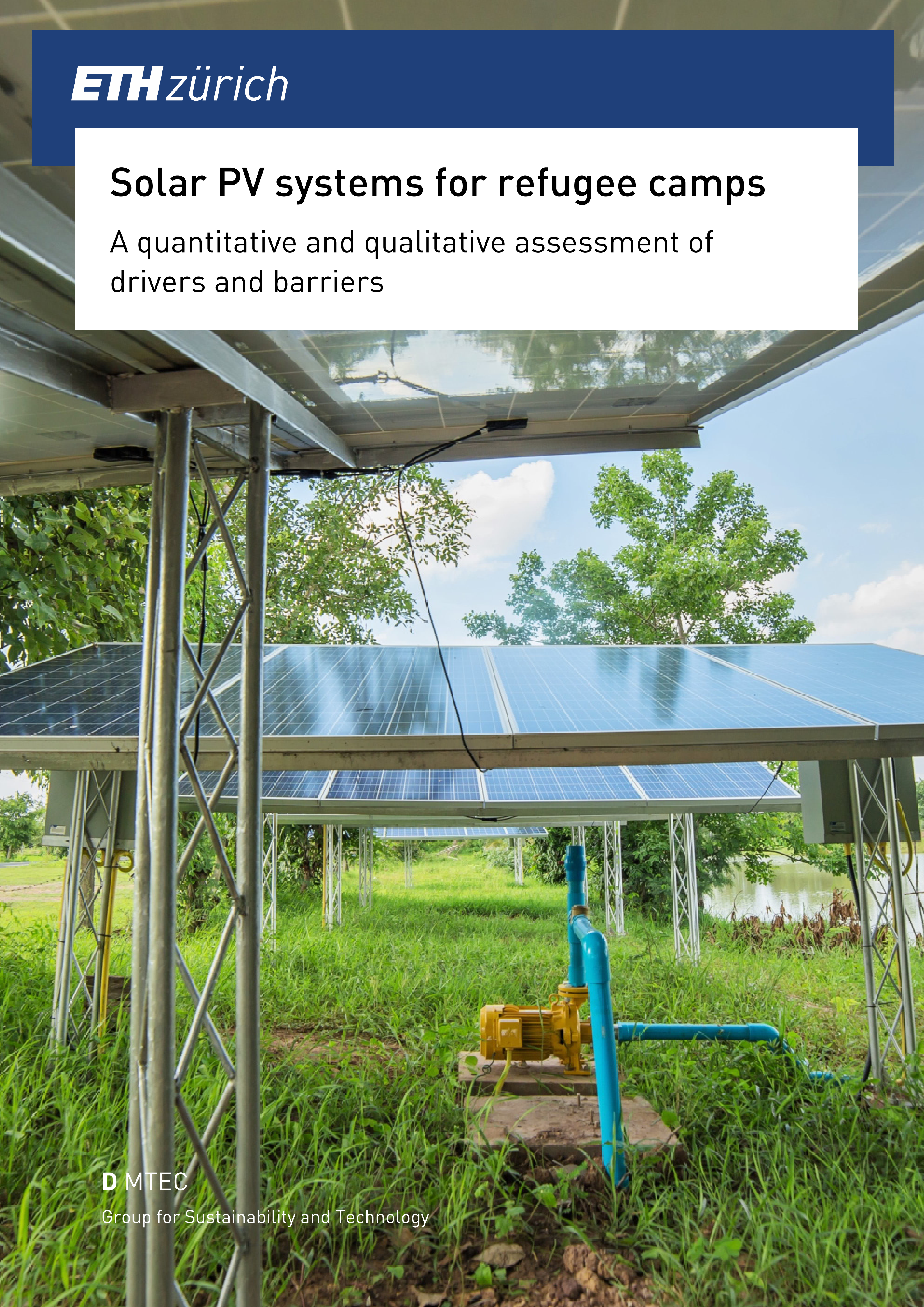

Solar PV systems for refugee camps

A quantitative and qualitative assessment of drivers and barriers

D MTEC

Group for Sustainability and Technology

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Cover image shows solar PV powered water pumping system in Thailand
Credit: WoraponL, shutterstock.com, ID 449888605

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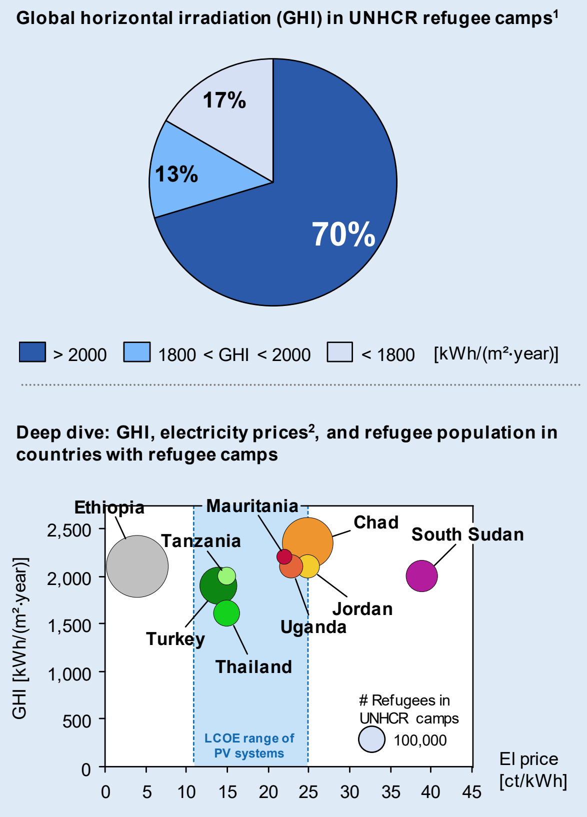
Introduction

In recent years, the role of the UN refugee agency UNHCR and other humanitarian agencies has changed significantly. Originally, these institutions were focusing on the provision of short-term, temporary emergency relief and operated under the premise that forcibly displaced people may eventually return home. However, statistics show that forcibly displaced people who find refuge in a camp remain there for an average of 17 years, which means that managing the corresponding settlements is a medium to long-term obligation that requires a dedicated strategy and novel operational competences (Jeffries, 2017; Lahn et al., 2015).

In light of these developments, the topic of energy demand and supply in refugee camps has gained increasing attention in recent years. Starting from the observation that "the costs of energy access and provision are unnecessarily high[1], whether measured in terms of finance, the environment, health or security" (Lahn et al., 2015, p. viii), UNHCR and other actors have launched initiatives such as the Global Strategy for Safe Access to Fuel and Energy, or the Moving Energy Initiative (Lahn et al., 2015; UNHCR, 2014). At the same time, a variety of different pilot projects started to bring clean energy technologies–such as solar photovoltaic (PV)–to the field and to position the humanitarian sector as a launch pad for sustainable development. Examples include the distribution of solar lanterns that allow camp inhabitants to light their shelters or charge mobile phones, or the installation of solar street lights that increase camp security and allow for communal activities after nightfall (IKEA Foundation, 2016). In addition to small-scale, decentralized solar solutions, the recent inauguration of two megawatt-scale photovoltaic (PV) power plants near the refugee settlements of Azraq (2MW) and Mafraq Za'atari (13MW) in Jordan demonstrate that solar PV systems can also be used to power vital infrastructure of entire camps (Hashem, 2017; Pyper, 2015).

However, even though solar PV provides a promising alternative to conventional forms of electricity generation, so far there has been no study that assesses to which degree the Jordan case is transferrable to other contexts. This assessment seems highly worthwhile since 70% of the largest refugee camps under UNHCR authority are located in areas with a global horizontal solar irradiation of more than 2000 kilowatt-hours (kWh) per square meter per year and in host countries with relatively high electricity prices (cf. Figure 1). While PV systems could leverage this irradiation to provide vital energy services to refugee camps–such as water pumping & purification, lighting, cooling, or communication–so far this potential remains largely untapped. This report seeks to address the gap in literature on this topic by studying the drivers and barriers to solar PV solutions in refugee camps.


Global horizontal irradiation (GHI) in UNHCR refugee camps¹

Deep dive: GHI, electricity prices², and refugee population in countries with refugee camps

¹ Analysis based on 308 entries in UNHCR (2014) camp database (planned, managed, reception, or transit camps); 80 largest camps by population shortlisted; GHI assessment possible for 54 camps; GHI data retrieved from SolarGIS

² Data shown represents retail electricity prices taken for city closest to refugee camp retrieved from World Bank (2016); PV LCOE assumes 20 year investment time horzion (conservative estimate)

Figure 1: Most UNHCR camps are located in areas with high solar irradiation and high electricity prices, which may render the installation of solar PV systems economically viable (ETH/SusTec analysis based on data provided by UNHCR, SolarGIS, and World Bank)

Based on the techno-economic model "Camp Electricity at Risk" we assess the levelized cost of electricity (LCOE) of four technological options to power a refugee camp's water pumping infrastructure: (1) the public grid; (2) diesel generators; (3) stand-alone solar PV systems; and (4) integrated solar PV+battery systems. Discussing the prospects of solar PV in a series of interviews with energy experts and top executives in humanitarian organizations, we subsequently render an overview of the economic, technical, social, and institutional factors that spur or inhibit the diffusion of solar PV and other clean technologies in refugee camps. We close by providing a number of practical recommendations for decision-makers in the humanitarian space.

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[1] Examples are a $800,000 monthly bill to power the Mafraq Za'atari camp in Jordan (Pyper, 2015) or a $400,000 per month water trucking operation to supply UNHCR settlements in Uganda (Llario, 2017).

Key findings

I. Water pumping provides a low-hanging fruit for kW-scale solar PV systems

According to the classification by Ziadé (2013) the energy service demands (ESD) of a refugee camp can be aggregated into three categories: (a) critical infrastructure such as water pumping or medical centers; (b) administrative facilities such as offices or staff accommodations; and (c) residual infrastructure such as street lighting, schools, or shelters. We decided to focus our assessment of solar PV solutions on the first category for the following three reasons. *First*, since most of their energy use is attributable to cooking and lighting, which is fueled by firewood, charcoal, or liquefied petroleum gas, refugees often have little to no direct electricity consumption[2]. Hence, improved cook stoves and basic solar lanterns appear most promising to alleviate extreme energy poverty in the short term. *Second*, by contrast, critical facilities are typically the largest energy consumers in a camp, and they mostly rely on electric power. In turn, solar PV systems that meet the electricity demand of critical infrastructure are usually larger in size (kilowatts (kW) to megawatts (MW)), which allows leveraging economies of scale. *Third*, motor-driven water pumping–an element of the critical camp infrastructure that is relevant from the emergency phase onward (UNHCR, 2017a)–has a load profile that is relatively flexible given that wells are often connected to water tanks for temporary storage. Therefore, the pumping power can be adjusted over time, which renders water pumping highly compatible with the intermittent nature of solar PV, even in the absence of a dedicated energy storage system.

Figure 2: Syrian refugees in front of water tanks–that are filled up by truck–at the Za'atari refugee camp in Mafraq, Jordan (2014); credit: Ehab Othman, shutterstock.com, ID 630281102

In addition, UNHCR provides a relatively comprehensive borehole database, which renders transferring the results of our analysis to the global scale less prone to assumptions than other ESDs. In sum, in line with recent analyses (IOM, 2017; Llario, 2017) water pumping seems to provide a promising use case for kW-scale solar PV systems. Therefore, an economic assessment is warranted to quantify that potential against the prevalent conventional energy sources.

II. Availability and uncertainty of input data renders the value of solar PV at risk

According to UNHCR, 80% of the boreholes in refugee camps under their management are not motorized today[3]. In turn, to tap water refugees use hand or foot pumps. The boreholes that are equipped with a motor predominantly rely on diesel generators (18%), while a minority is connected to the local grid (1%) or has been "solarized" (2%), which means that it has been attached to a solar PV system. While rendering a realistic estimate for the costs that accrue to refugees from manual water pumping goes beyond the scope of our study, our analysis includes the other aforementioned technologies: grid; diesel; and solar PV. In addition to stand-alone solar PV, we incorporate an integrated PV+battery system, which allows us to estimate the additional cost for a solar solution that grants multiple hours of autonomy[4]. Following a purposeful sampling approach, we select three particular refugee settlements managed by UNHCR as a basis for our empirical analysis: Mafraq Za'atari in Jordan, which recently gained international recognition due to the installation of a nearby PV system; Harran-Kokenli in Turkey's Sanliurfa province, which represents one of the most modern camps and is connected to the public grid; and the Dadaab camps in rural Kenya, one of the largest and oldest refugee settlements in the world.

Table 1: Overview of camp-specific input data

	Mafraq Za'atari Jordan	Harran-Kokenli Turkey	Dadaab Kenya
Climate	Desert	Mediterranean	Desert
Population[a]	84,773	14,195	352,549
Water source	~ 3 boreholes	Pipeline, dam	~ 28 boreholes
Energy source[b]	Grid	Grid	Diesel
Water demand[c]	1695 m^3/day	284 m^3/day	7051 m^3/day
Pumping height[d]	453m	~20m	175m
WACC[e]	13.7%	10.8%	13.5%
Annual PV yield[f]	1,846 kWh/kWp	1,682 kWh/kWp	1,536 kWh/kWp
PV system cost[g]	$1.50/Wp	$1.37/Wp	$2.00/Wp
Diesel price[h]	$0.67/l	$1.23/l	$0.86/l
Grid distance[i]	0 km	0 km	250 km
Electricity price[j]	$25 ct/kWh	$14 ct/kWh	$18 ct/kWh
CO_2 emissions[k]	1,250 g/kWh	534 g/kWh	1,465 g/kWh

a: UNHCR, 2014, b: for pumping, c: based on actual or UNHCR manual based water demand per capita; d: based on UNHCR or own estimate; e: weighted average cost of capital, based on WACCexpert.com for utility sector; f: based on SolarGIS; g: US dollar per watt-peak estimates from Trina Solar; h: based on Global Petrol Prices; i: own, based on geni.org and Google Earth; j: retail electricity price based on local utility data; k: emission intensity of electricity mix based on IEA, 2016

While all of the camps have been identified as suitable[5] for the installation of a solar PV system by an expert in the research team, they significantly differ across a number of relevant dimensions (cf. Table 1). In addition, many of the parameters are uncertain or unknown. For example, after conducting a survey in the Dadaab camp in 2015 the Moving Energy Initiative concluded that "[…] data on electricity generation and

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[2] For example, even though the Azraq camp hosts refugees who are used to a relatively high living standard from their home country Syria, "1kWh/day [is] enough power to operate lights, a refrigerator, television, a fan and charge phones." (UNHCR, 2017b).

[3] In addition, many camps rely on high cost, high polluting water trucking. While a detailed assessment was beyond the scope of this study, our estimates show that boreholes with solar water pumps consistently provide the less costly and emission-intensive lternative.

[4] An overview of technology-specific input data is available on request.

[5] A member of our research team has a professional background in developing utility-scale solar PV projects around the world.

consumption in the camp are patchy [… not capturing] important parameters such as the amount of electricity generated, overall electricity demand and supply scenarios, and the unit cost of generated electricity" (MEI, 2016, p. 6). As a consequence, while some of the input values of our analysis are fixed, the critical ones are distributed across a specific range. To cope with the underlying uncertainty and allow for such stochastic inputs, we implemented our techno-economic model–Camp Electricity at Risk–as a Monte-Carlo simulation[6].

III. Solar PV systems provide a viable alternative to conventional energy solutions for water pumping

As shown in Figure 3, the levelized cost of electricity differs significantly, both across the four technological options and across the three focal camps. For Mafraq Za'atari in Jordan we find that for an investment period of 10 years, solar PV provides the least cost option, generating savings of about $10ct/kWh compared to a diesel generator or electricity drawn from the public grid. Insofar, our results underline the strong economic case for the recently installed 13MW PV power plant near Mafraq, which indicates that our model passes the reality check.

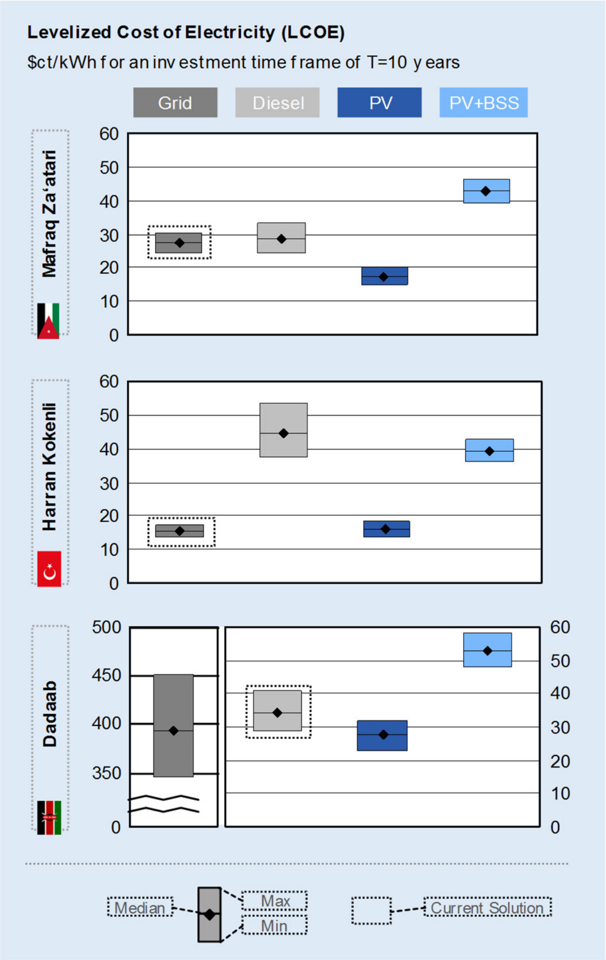

Figure 3: Minimum, median, and maximum values of levelized cost of electricity (LCOE) for four alternative technological options to serve the water pumping demand of three particular refugee camps; based on techno-economic model Camp Electricity at Risk

For the container city of Harran Kokenli, the LCOE estimates show that a stand-alone solar PV system cannot compete with electricity provided by the local grid on a pure cost basis. The reason is that, even though the solar PV LCOE value is the lowest among the analyzed camps, Turkey has very low retail electricity prices. However, given that the LCOE values for the grid and solar PV are almost identical for an investment period of 10 years, it seems reasonable to assume that the installation of a PV system may entail cost savings over the longer run. The analysis for the Dadaab camps reveals the impact of high interconnection costs of a remote and spatially dispersed refugee settlement. In the hypothetical case these costs were levelized over a 10-year period, the resulting grid LCOE would range between $3.50/kWh and $4.50/kWh. By contrast, the LCOE of the currently predominant energy source for motorized water pumps–the diesel generator–are considerably lower, ranging between $30-40ct/kWh. Similar to the other two camps, levelized cost could be significantly reduced down to the level of about $25ct/kWh by solarizing the Dadaab water pumping systems.

For all of the examined camps we find that from an economic perspective solar PV provides a highly attractive alternative to conventional solutions for water pumping, even for a relatively short time horizon. Our results also reveal that investing into an integrated PV+battery system, which grants 12 hours of autonomy, entails a relatively high levelized cost of electricity, which is due to the high upfront capital cost of the lithium-ion battery and the short investment time horizon of 10 years. While the additional costs seem hard to justify for a use case like water pumping–where storing water in tanks may serve as an alternative form of energy storage when excess pumping power is available at midday–it should be noted that PV+battery systems may provide a mature and cost-effective energy source for other critical infrastructure items such as health centers. In light of the recent cost decreases in battery manufacturing, it seems reasonable to assume that the latter case will gain relevance in the near future (Nykvist and Nilsson, 2015).

Table 2: Sensitivity analysis; top parameters increasing or decreasing (-) LCOE

#	Grid[a]	Diesel	PV	PV+BSS[b]
1	Electricity price	Efficiency	System cost	System cost
2	System cost	Fuel price	WACC	DoD[c] (-)
3	WACC[d]	O&M[e] cost	Irradiation (-)	O&M cost

a: Order of top sensitivities for grid depends on whether interconnection costs of the camp are applicable; b: Top 3 sensitivities identical with stand-alone PV; hence focus on BSS items; c: depth of discharge; d: weighted average cost of capital; e: operation and maintenance

Table 2 reveals which of the techno-economic input parameters have the largest impact on the estimated LCOE of each technology configuration. While the parameters that decrease the cost of PV or battery systems can be regarded as direct drivers of the corresponding technologies, the parameters that lead to a cost increase of grid and diesel–all else equal–can be considered indirect drivers of solar PV.

IV. Solar water pumping can help reduce cost and save emissions in refugee camps

In addition to LCOE, we approximated the total cost and emission savings for each camp based on the differential between the status quo technology and the least-cost option. To account for the capital intensity of PV and battery systems, we estimate the benefits of switching for investment time frames of 5, 10, 15, and 20 years. As shown in Figure 4, we find that–with

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[6] Details (model, results, assumptions) available on request.

the exception of the camp in Turkey–a switch to solar PV entails significant cost and emission savings. According to our estimates for the Mafraq Za'atari camp, the UN refugee agency could achieve discounted cost savings of about $860,000 over 20 years. Similar savings can be achieved in Dadaab but over a considerably shorter period of only five to six years. After 20 years, almost $1.7 million can be saved through solar water pumping in Dadaab, which is in line with the recent trend to solarize existing boreholes and extend water tank capacity in the corresponding refugee settlements. The switch to solar PV may also yield significant CO_2 emission savings. In Mafraq 21,000 tons CO_2 equivalent can be saved over 20 years, whereas in Dadaab cumulative emission savings amount to about 30,000 tons.

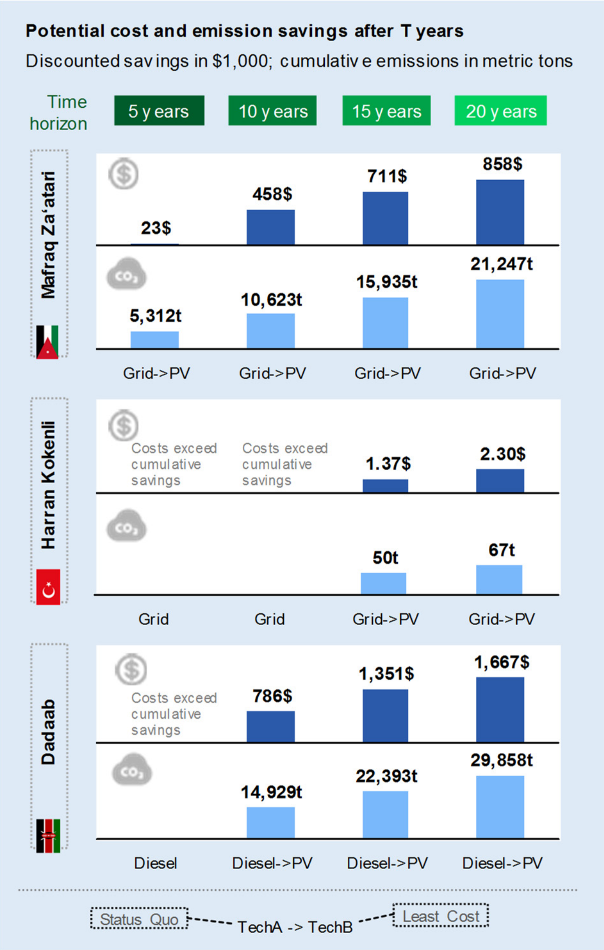


Figure 4: Potential cost (discounted net present value) and emission savings (cumulative) from switching between technologies and fuel types to power water pumps; investment time horizons between 5 and 20 years; all values reflect median of outcome distribution; based on techno-economic model Camp Electricity at Risk

In other words, the abatement costs of CO_2 emissions for both of the aforementioned camps are negative, which indicates that it would be misleading to frame sustainable and affordable energy as a tradeoff. Without implying that Mafraq Za'atari is representative of the 224 camps managed by UNHCR in 2014, extrapolating[7] this case to the global scale suggested potential *cost savings* of more than *$43 million* and *emission reductions* of *1 million tons* over a 20-year timeframe–in the domain of water pumping alone.

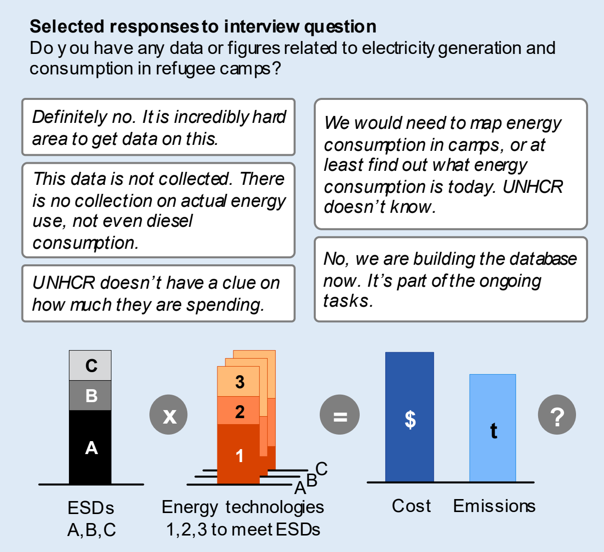
In sum, since it appears likely that a switch to solar PV in the domain of water pumping could entail a spillover effect on other end uses across the categories outlined in section 1, it seems reasonable to position the aforementioned estimates as a lower boundary for the camps' total cost and emission savings potential. In addition, the finding that switching to PV eventually pencils out even in an economic setup as detrimental[8] to solar PV as Harran Kokenli in Turkey, underscores the potential of solar PV across a wide range of empirical cases.

V. Several barriers must be addressed to unlock the benefits of solar PV for refugees and host communities

Based on the purely techno-economic assessment outlined above one could wonder why water pumping systems based on solar PV have not yet seen wide deployment in refugee camps around the world. To answer this question, we confronted ten experts from leading organizations in the humanitarian sector (cf. Figure 8) with our findings. Thereby, we learned that a number of socio-institutional barriers exist that impede a more rapid diffusion of solar PV systems in refugee camps. In the following, we synthesize and translate the key barriers into five action items to be addressed by decision makers in humanitarian agencies, host country governments, or private firms.

Item 1: Introduce energy demand and supply accounting

As illustrated in Figure 5, our interviewees unanimously agreed that the lack of data on energy demand and supply in refugee camps is one of the key reasons for the limited awareness about the significant cost and emission saving potentials.


Selected responses to interview question
Do you have any data or figures related to electricity generation and consumption in refugee camps?

Definitely no. It is incredibly hard area to get data on this.

This data is not collected. There is no collection on actual energy use, not even diesel consumption.

UNHCR doesn't have a clue on how much they are spending.

We would need to map energy consumption in camps, or at least find out what energy consumption is today. UNHCR doesn't know.

No, we are building the database now. It's part of the ongoing tasks.

Figure 5: Our interviewees highlighted the lack of reliable data to estimate energy demand and supply in refugee camps, and stressed the importance of energy accounting as a prerequisite for the diffusion of clean technologies

For example, while supplying a remote refugee camp with fuel and water by truck is one the most costly and highest polluting options, in the emergency phase of a refugee crisis, it may be the best-suited response to alleviate life-threatening situations. The problem is that, once set up and running, these inefficient procedures reinforce themselves and often remain in place over

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[7] Linear extrapolation based on population data.

[8] Switching to PV only makes sense if investors accept a long payback period or low rate of return.

protracted time periods. Previous studies such as Lahn et al. (2015) have highlighted the need for action in this domain. But despite the common wisdom that you cannot manage what you cannot measure, the current absence of energy accounting practices for camps in the post-emergency phase inhibits the widespread introduction of clean energy technologies such as solar PV.

To render realistic estimates–e.g. based on the method[9] outlined in this study–a standardized monitoring system should be implemented to collect and assess energy demand and supply during the post-emergency phase. This tool should be easy to access and well known to all relevant stakeholders of the camps' energy ecosystems, e.g. by integrating it into existing manuals (Birkeland et al., 2008; UNHCR, 2014). While the user interface for data collection–ideally digital and compatible with mobile devices–should be as self-explaining and effortless to use as possible, upfront training and adequate incentive structures should be provided to create awareness for the importance of the task and illustrate the benefits of the exercise. Developing the tool in close cooperation with the end users–e.g. camp administration, utility firms, refugees–is strongly recommended to leverage field-level expertise and increase the likelihood of acceptance and application. Whenever possible, measurements should be taken to capture the load profile of the most relevant energy consumers over time, to decide whether the prospective solar PV installations need to be equipped with some form of storage system. The data should be stored in a web-based, openly accessible repository that can be drawn on for statistical evaluation, e.g. to prioritize energy interventions. To speed up the process of developing the corresponding toolkits, UNHCR could draw on readily available open source code, or organize a dedicated hackathon event to have highly skilled, intrinsically motivated labor develop a low-cost but robust pilot solution that can be tested and further developed in the field.

Item 2: Develop clean energy and solar PV expertise in the humanitarian sector as well as in the field

A systematic energy accounting scheme as outlined in Item 1 would only be functional, if sufficient expertise on the topic of energy was available at key entities in the humanitarian sector (UN, NGOs, donors, universities, private sector), as well as in the camps and the surrounding communities. However, only recently have international agencies such as UNHCR begun to form dedicated organizational entities responsible for consolidating best practices, expand or build up internal know-how, and bundle resources. The necessity for doing so is revealed in archival data that shows numerous promising solutions have been tried out before, but the lessons learned were–at best–only shared within the corresponding expert community, and mostly on an ad hoc basis. Creating a continuous multi-stakeholder forum and widely disseminating the results of this discussion beyond promising camp-level interagency task forces may subsequently prompt a dedicated agenda on energy for displaced people (MEI, 2018, 2016, p. 6).

However, even in case clean energy will be embraced as a strategic priority by humanitarian agencies, the experts we interviewed highlighted that many camp-level projects still suffer from a lack of technical expertise on site. This includes administrative staff, the refugee population[10], as well as host communities, and is especially evident in developing countries. In turn, it can be assumed that the insights gained from Item 1 can only be brought to life, if they are coupled with a comprehensive training program for the aforementioned groups on how to select, purchase, install, operate, and maintain solar PV systems. Recent initiatives, such as a solar energy education program for Syrian refugees in Jordan provided by the Norwegian Refugee Council (NRC) in cooperation with iPlatform (NRC, 2016), have shown that "there is real demand and value". Solar PV as a modular technology is particularly well-suited to teach and demonstrate the basics of electrical engineering, since its components are available at the watt scale–where they are inexpensive and plug-and-play–but many of the course insights and skills are applicable to the megawatt scale.

Figure 6: Solar PV system in village near Chiang Mai, Thailand (2010); credit: shutterstock.com, ID 205773730

In other words, once users understand solar PV on a micro level, they can easily handle the technology on a macro level. Thereby, solar PV in refugee camps offers a promising option to leapfrog conventional power generation technologies and realize sustainable development goal (SDG) 7 by ensuring access to affordable, reliable, sustainable and modern energy for all. To do so, expertise from developing energy supply in rural areas can potentially be transferred to the humanitarian sector (cf. Figure 6). Thereby, the technology may help reduce the risk of even more people being "displaced from their homes due to climate change" (Biermann and Boas, 2008; IPCC, 2014, p. 1027f). In doing so, solar PV may provide the basis for modern water & sanitation systems (SDG6), become a cornerstone of resilient infrastructure (SDG9), and spur economic growth (SDG8).

Item 3: Develop viable PV financing and repayment schemes

As shown in the literature, the economics of solar PV are affected more by the cost of capital than by the solar irradiation level (Ondraczek et al., 2015). In turn, access to cheap finance is a key driver behind solar PV diffusion. However, since many refugee camps are located in low to middle-income countries characterized by a weak energy infrastructure–both physically and administratively–investors usually demand a significant risk premium. Therefore, depending on the context it may be necessary to couple clean energy investments with particular

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[9] The Camp Electricity at Risk model has been designed to include all three energy demand categories outlined in section I and can be applied to any camp as soon as the corresponding input data is available.

[10] The extent to which the camp population can be included in such projects depends on whether refugees are granted work permits by the host country authorities.

derisking measures, or ideally to integrate them into the host country's overarching derisking strategy (Waissbein et al., 2013).

In addition, solar PV investments–like many renewable technologies–are capital intensive, which means they may only break even after a certain time period. By contrast, due to their annual budgets, the time horizon of UNHCR and other humanitarian agencies is typically less or equal to one year. However, the first year savings usually do not suffice to pay back the investment cost of a solar PV system, which therefore favors energy technologies with low upfront and high operating cost, i.e. diesel generators. The 13MW PV plant, which recently went online near the refugee camp of Mafraq Za'atari in Jordan, is a particularly useful case to illustrate how to overcome this issue by leveraging to a win-win situation for multiple stakeholders[11]. The project was realized based on a public-private partnership, which allows the UNHCR to achieve significant cost savings once the plant goes online. This is possible due to a so-called power purchase agreement (PPA). This financing scheme–which is increasingly common for renewable energy projects around the world–stretches the investment and capital cost over a specific time horizon. Typically, the energy consumer enters a 20-year contract, which grants the power plant owner the payback of and a specific return on his investment. An international tender ensures low installation costs by leveraging the competition between PV plant developers. Since the refugee camp is connected to the public grid, the solar PV project also helps Jordan achieve its renewable energy target. The excess energy coming from the camp's solar PV plant is fed into the public grid and remunerated based on a Net Metering agreement with the local utility (Ossenbrink, 2017). While the stakeholder constellations may significantly vary in other camps, the Mafraq case holds valuable lessons learned for how innovative financing and repayment schemes can be designed that account for the current institutional frameworks of entities in the humanitarian sector.

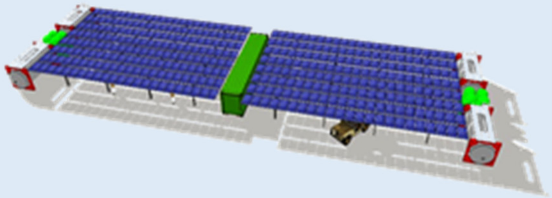
Item 4: Develop PV system designs that address the needs of refugee camps

Our interviewees pointed us to several socio-institutional adoption barriers of solar PV, which could be ruled out through technical designs geared towards the context of refugee camps. Figure 7 lays out three examples. Layout (1) shows a containerized 100kW turnkey solar PV plant, which is inspired by experts frequently stating two reasons for deploying diesel generators instead of PV systems: their rapid deployability, which is crucial in emergency situations; and their redeployability, which allows framing refugee camps as temporary, thereby increasing the acceptance of host communities. The depicted design–similar to a pilot plant that has been deployed in Ethiopia (PWRstation, 2016)–is capable of meeting the aforementioned requirements, while achieving the techno-economic benefits outlined in the previous sections. However, its viability for emergency situation depends on whether UNHCR or other agencies are willing to invest and keep up a stock of containerized PV systems that are readily available and rapidly deployable in case of an imminent refugee crisis. Layout (2) illustrates a solar PV system that is attached to a redeployable water pumping, purification, and storage system, which builds on four smaller tank containers. The latter act as a support structure for beams and purlins of a solar canopy that may host a community hub underneath which appears reasonable given that water wells are usual gathering points in refugee camps. The elevated position of the solar PV modules allows for all electricity cables and water pipes to be suspended overhead so that no underground electricity cables are required. The whole system may be constructed to stand on its own dead weight and without any foundation works, and its modular design allows deployment of different canopies next to each other depending on the desired pumping capacity. Layout (3) sketches a combined solar PV and battery storage system that is deployed from a refrigerated container.

Exemplary PV configurations geared towards refugee camps

(1) Redeployable 105 kW solar PV generator in 40 foot dry container

(2) 100 kW solar PV modular canopy attached to a redeployable water pumping and purifying station



(3) 100 kW hybrid solar PV generator with 200 kWh battery system

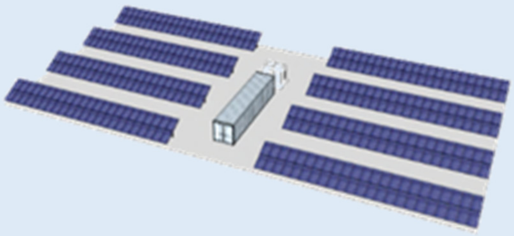


Figure 7: Layout of three exemplary, 100kW size, turnkey solar PV configurations; (1) a redeployable solution for emergency response; (2) an integrated solar water pumping and purification facility; (3) an integrated PV+battery storage facility

The latter may be used to store temperature-controlled products such as vaccines. This configuration addresses the concern of limited security of supply provided by stand-alone solar PV systems, which may inhibit the technology's applicability for a wider range of use cases. The current design–which has been analyzed as part of the techno-economic assessment outlined in section III–is able to store half of the day's average PV electricity yield and serves four hours of peak demand after nightfall. Each of the three designs can be deemed realistic and ready to implement, and they may render preconceptions about some of the barriers to solar PV obsolete. However, so far there are no adequate financing measures for such mid-scale PV systems, especially when it comes to first-of-its-kind pilot projects. UNHCR should therefore consult with the relevant stakeholders on how to allow for context-specificity

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[11] The key stakeholders include UNHCR, the Jordanian Ministry of Energy and Mineral Resources, the Ministry of Planning and International cooperation, the National Electric Power Company, and the German Development Bank KfW.

while avoiding overly fragmented approaches, and assess whether scale effects can be leveraged, e.g. through framework agreements with manufacturers or bulk deployment of such systems.

Item 5: Spur diffusion of complementary technologies to leverage network and spillover effects, build entrepreneurial activity, and empower refugees and host communities

The innovation literature has shown that the deployment of complementary technologies is mutually reinforcing. Inversely framed, the absence of one technology may inhibit the growth of another, or even culminate in a chicken-and-egg problem. In the case of PV, the rapid cost decrease and diffusion of consumer electronics[12], telecommunication infrastructure[13], and battery storage are likely to significantly spur the demand for or enhance the performance of solar PV systems. In the context of the humanitarian sector, these co-developments are reflected in a series of entrepreneurial activities in refugee camps. For example, charging light torches or smartphones via PV panels is a common micro business in almost all camps, whereas the more sophisticated approaches include rentals of TVs or entire solar home systems under pay-as-you-go (PAYG) schemes. While these developments underscore the significant ability and willingness to pay to meet 21st century energy service demands through modern forms of energy supply, they also underscore the urgency of Items 1-4, should future investments into fossil fuels be avoided and the unsustainable technology lock-ins finally overcome.

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Figure 8: Our interviewee sample comprises a number of different entities active in the humanitarian space

About the report

This study has been developed based on a Master thesis at D-MTEC, ETH Zurich, in cooperation between the Group for Sustainability and Technology (SusTec) and Trina Solar Switzerland. Please note that the views expressed are those of the authors and do not necessarily reflect those of the ETH. The report describes research in progress and is published to add to the debate and elicit comments. In case you want to learn more about the findings or discuss details of the analysis such as the Camp Electricity at Risk model, please feel free to contact us.

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[12] Examples include the radio, the TV, the PC or the smartphone.

[13] Examples include mobile networks enabling mobile payment or remote measuring.