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UKRAINE SUSTAINABLE ENERGY LENDING FACILITY (USELF)

Renewable Energy in Ukraine Technical Report: Solar

One of five technical reports on Renewable Energy for the USELF Strategic Environmental Review

USELF RENEWABLE ENERGY IN UKRAINE
PROJECT SCENARIOS: SOLAR

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Details of document preparation and issue:

Version N°	Prepared by	Reviewed by	Authorised for issue	Issue date	Issue status
v1	Mon Hong (others to be added)	Mon Hong	Jay Abbott	May 11 2011	EBRD Bank Draft
v2	Mon Hong	Mon Hong	Jay Abbott	September 1, 2011	EBRD Bank Draft
v3					

B&V project no. 167767 Client's reference no. TCS ID 29098

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USELF RENEWABLE ENERGY IN UKRAINE
PROJECT SCENARIOS: SOLAR

1. INTRODUCTION

The purpose of this technical report is to provide the USELF Strategic Environmental (SER) team with a representative scenario for solar development in Ukraine as the team develops the SER report. The analysis examines potential locations, technologies and operating conditions for the solar scenario. It focuses on the technical constraints associated with the availability of the resource and the technologies that employ the resource, but does not address environmental and socioeconomic constraints that will be discussed in the SER separately. This is not intended to preclude or limit the future development of other technologies that have not been identified here for review.

The report is organized into two sections:

- Resource and Potential
- Technology Characteristics

Section 2 (Resource and Potential) of the report provides the SER process with country-specific background of the availability and quantity of the solar resource, as well as potential locations or higher concentrations in Ukraine.

Section 3 (Technology Characterstics) describes the technologies that employ the resource for electricity production and details the performance characteristics, land requirements, interconnection and operations and maintenance needs of the technology, as well as the availability of the technology components in Ukraine. The section also examines typical site considerations and construction activities associated with solar projects as inputs to the SER report.

The focus for this report is on large utility-scale solar photovoltaic (PV) projects that are ground mounted and interconnected to the transmission grid, as required by the Green tariff.

2. SOLAR RESOURCE AND POTENTIAL

The solar resources in Ukraine should be sufficient to support large utility-scale solar projects under the existing Green Tariff for solar photovoltaic (PV) installations in most areas of the country, with the exception of the westernmost oblasts and mountainous terrain areas.

2.1 Proposed Solar Projects

The utility-scale solar PV projects being proposed in Ukraine are primarily located in Crimea, Odessa, and Kyiv. Some examples of these projects that are announced are shown in Table 2-1. These range from 20 to 100 MW per site.

Table 2-1. Announced Solar PV Projects.

Project	Location	Oblast	Capacity (MW)	Sponsor
Okhotnykove PV PP	Okhotnykove (Saki district)	Crimea	100	Activ Solar
Perove PV PP	Perove (Simferopol district)	Crimea	80	Activ Solar
Trudove PV PP	Trudove	Crimea	100	Activ Solar
Rodnykove PV PP	Rodnykove	Crimea	20	Activ Solar
Krim Sinosol PV PP	Krim region	Crimea	20	Sinosol AG
Source: www.ebrdrenewables.com.				

2.2 Solar Resource Areas

The sample sites for solar resources in **Error! Reference source not found.** show that Crimea and southern Ukraine have the best resources for solar PV development. Central and eastern parts of Ukraine also have moderately good solar resources for development, but economics, hilly/mountainous terrain and selection of technologies will need to be considered. As for the western part of Ukraine, the combination of less favorable resources and more rugged terrain makes large utility-scale solar in this region challenging.

Table 2-2. Representative Performance by Technology and Region.

	Insolation GHI**(kWh/ m^2)	Capacity Factor*			
		Crystalline Fixed Tilt	Thin Film Fixed Tilt	Crystalline 1-axis tracking	Crystalline 2-axis tracking
Crimea/Odessa (south-coastal)	1,357	16%	17%	18%	22%
Kyiv (central)	1,197	15%	15%	16%	20%
Donetsk (east-south)	1,192	15%	15%	16%	20%
L'viv (west)	1,056	13%	13%	14%	17%

Notes:
*Estimated capacity factor at the point of interconnection.
** Global horizontal irradiance

Crimea/Odessa: Crimea and Odessa have similar solar resources and have large areas of relatively flat land for large-scale utility development. The southern portion of Crimea is mountainous and will likely not have the area of flat land required for 1+ MW solar PV installations. Similarly, northwestern parts of Odessa are hilly, so development in southern Odessa is preferred. The greatest development potential are in these oblasts.

Eastern Ukraine: The solar resources in this area are moderate. Development of solar projects in this area would need to be in relatively flat contiguous areas. Since a part of eastern Ukraine is the agricultural center for the country, development of solar projects may compete with land use for food production and pasture.

Central Ukraine: Similar to eastern Ukraine, the solar resources in this area are moderate, but there are some opportunities with flat contiguous areas for large solar development.

Western Ukraine: Opportunities for large-scale solar development is limited in western Ukraine oblasts such as Volyn, L'viv, Ivano-Frankivsk, Zakarpattia and Ternopil due to lower quality solar resource and more rugged terrain.

2.3 Solar Resources and Transmission

Figure 2-1 depicts the daily average global horizontal irradiation (GHI) in Ukraine.

Since solar is available everywhere, the potential for utility scale projects of 1 MW or greater is limited by the availability of land for PV installations, economics of specific sites, and connection to local distribution and transmission systems. There may be some export limitations in Crimea if extensive wind projects are developed along with solar. The development scenarios for solar by region are shown in Table 2-3 under two scenarios of development: Solar Only and Solar Combined with Wind.

The best solar resources are in Crimea and Odessa, so the solar development will be greatest in those oblasts. In Dnipro, the only limitation is the local load, since there is extensive transmission in the region. Though the solar resource is not as good (less profitable) as in Odessa and Crimea, the estimated 4000 MW of solar PV potential would occupy around 15,000 hectares of land or 150 sq. km. Most of the solar PV development estimated for Dnipro would occur in Zaporizhia.

The Donbass, northern, southwestern, and western regions are assumed to have no solar PV development, as the regions have less optimal solar resources and face hilly or mountainous terrain.

For more detailed discussion of the transmission constraints related to solar PV development, refer to Appendix B.

Table 2-3. Estimated Maximum Solar Development

Regional Electric Power Systems	Oblast	Regional Solar-Only Development Scenario (MW)	Regional Solar Development Combined with Wind Scenario (MW)
Central	Cherkasy Chernihiv Kyiv Zhytomyr	1,800	571
Crimea	Crimea	2,839	710
Dnipro	Dnipropetrovsk Kirovohrad Zaporizhia	3,980	1,001
Donbass	Donetsk Luhansk	0	0
Northern	Kharkiv Poltava Sumy	0	0
Southern	Kherson Mykolaiv Odessa	1,281	320
Southwestern	Chernivtsi Khmelnytskyi Ternopil Vinnytsia	0	0
Western	Ivano-Frankivsk L'viv Rivne Volyn Zakarpattia	0	0
Total		9,900	2,602

Source: Black & Veatch analysis.

3. TECHNOLOGY CHARACTERISTICS

This section discusses three types of utility-scale solar photovoltaic (PV) projects that were identified in the scoping report: small solar PV systemss ranging from 1 – 5 MW in capacity, medium solar PV systems ranging in sizes from 5 – 20 MW capacity, and large solar PV plants above 20 MW of capacity.

3.1 Components and Configuration

A PV system has three critical components: PV modules, inverters, and racking. In addition, the interconnection infrastructure at a medium or high voltage is especially important for medium and large PV projects. Other components known as the Balance of System include wiring, combiner boxes, disconnection switches, meters, and monitoring equipment. Figure 3-1 and Figure 3-2 present schematics of typical solar PV systems and components.

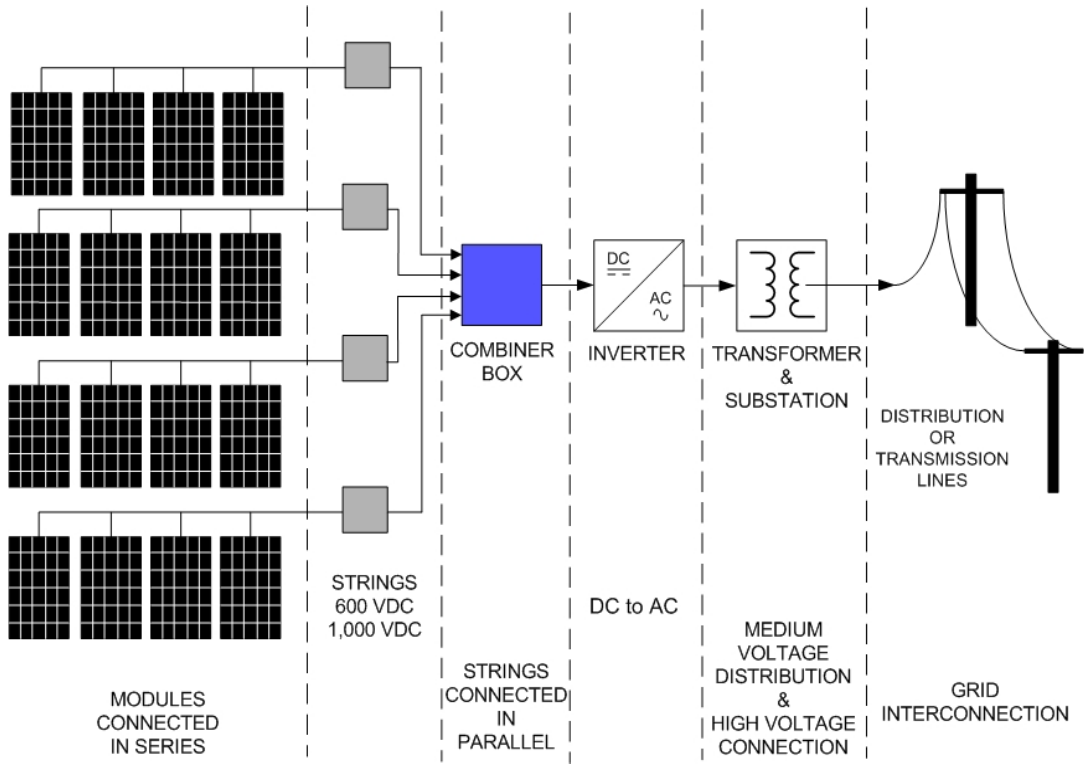


Figure 3-1. Conceptual Overview of a Solar PV System

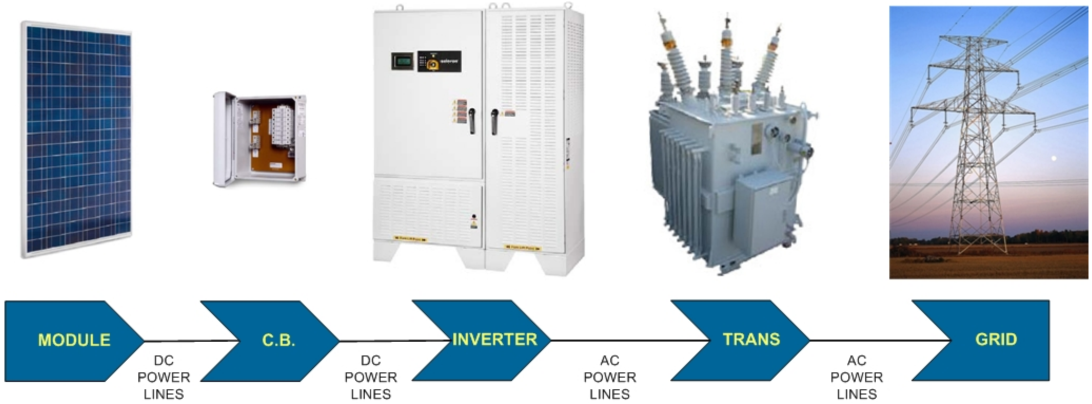


Figure 3-2. Typical PV Components

- **PV Modules and Strings:** Flat-plate PV modules are divided into two broad technology categories: crystalline silicon and thin-film. Crystalline silicon PV modules used for these types of projects are typically on the order of 100 cm wide by 190 cm high with a 1 cm anodized aluminum frame and a weight of around 25 kg. Thin-film modules are smaller (half the size) and have two layers of glass, with no frame.

  PV modules made with crystalline silicon cells are more efficient and produce more electricity per area of coverage compared to thin-film. The modules take up about 0.85 hectares per MW, while the overall project requires about 2.6 hectares per MW[1]. Thin-film modules, on the other hand, offer some economic advantages over crystalline silicone modules as they are generally cheaper to produce. These modules take up about 1.1 hectares per MW, while the overall project requires approximately 4.5 hectares per MW[2] of installed capacity, double the space than crystalline silicon.

  From an electrical interconnection perspective, modules are connected in series to form strings. Several strings are then connected in parallel in a combiner box. The output of several combiner boxes in the system is in turn connected to a central inverter which converts the DC current generated by the modules into AC current.

- **Inverters and Transformers:** The inverter is the main component of the power conversion unit of the system, converting the DC current generated by the modules into grid quality AC current. For the systems being considered in the SER, a typical power conversion unit makes use of two large capacity inverters that integrate a power conversion unit with a typical capacity between 1 and 2 MW. This type of PV design is also known as a central inverter configuration with typical conversion efficiencies between 97 and 98 percent.

  For systems of the scale being considered in the SER, the output of the inverter is connected to a transformer that elevates the voltage to a distribution level. The collection of all the transformers output occurs at the switchyard, which can also be the point of interconnection to the grid via a substation. For utility-scale projects the output of the switchyard is elevated to either distribution or transmission voltage before interconnection to the grid.

[1] Typical ground mounted system at a fixed tilt with 30 percent ground coverage ratio and rated around 1,2 MWp,
[2] Same characteristics as above

- **Racking:** Racking systems provide a structural support for the modules. The materials and design of the rack have to withstand exposure to the elements during the lifetime of the project. Racking systems are typically made of galvanized steel and aluminum to prevent corrosion. The structural integrity of the racking system has to be certified to withstand seismic (if applicable) and wind forces for wind gusts of over 80 km/hr (typically). Racking systems are either fixed or designed with a mechanism that tracks the sun in an effort to maximize the power produced by the solar system. Typical tracking systems are horizontal, single-axis and dual-axis. Figure 3-3 illustrates these different types of racking systems. The production profile of these different systems will vary, with the dual axis tracker providing the most energy generation per day and the fixed tilt the lowest. The higher costs associated with the dual axis tracker and expected revenues may make a fixed tilt system more attractive to implement, however.

Fixed Tilt

Single-Axis Tracking

Two-Axis Tracking

Figure 3-3. Solar PV Racking Systems

Figure 3-4 shows a 1.0 MW capacity fixed-tilt crystalline silicone PV facility installation. Larger projects would increase in size in equal increments.

Figure 3-4. Typical 1 MW Capacity Fixed Tilt Solar System

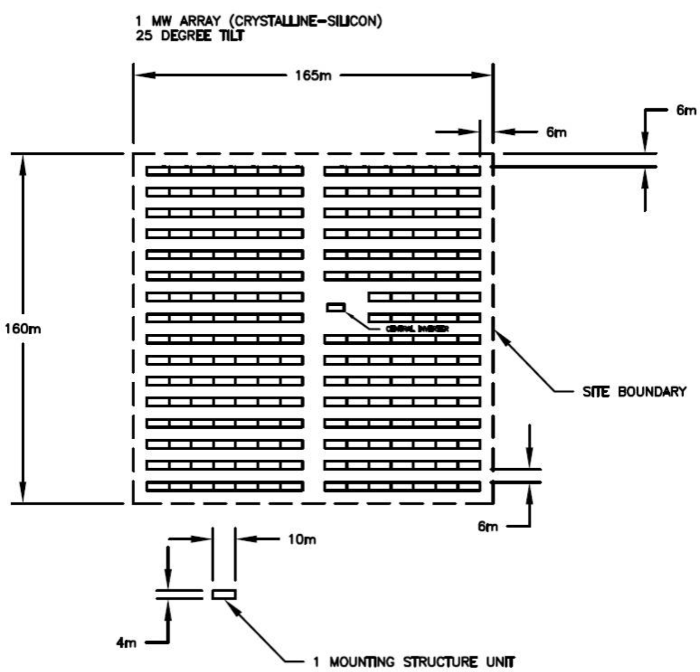


Figure 3-5. 1 MW Crystalline Silicon Fixed Tilt

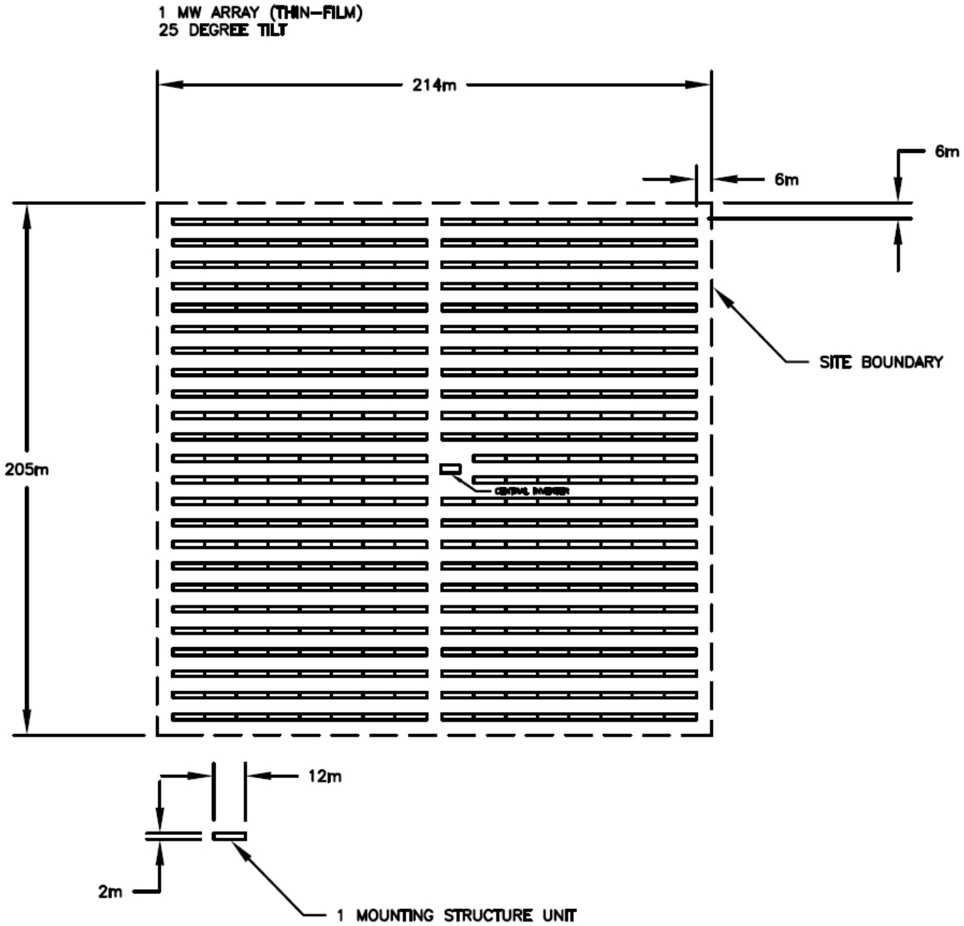


Figure 3-6. 1 MW Thin-Film Fixed Tilt

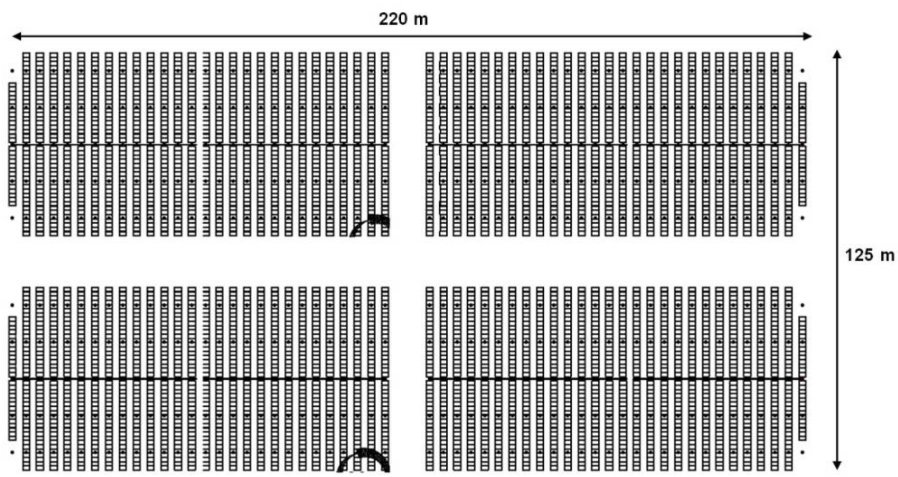


Figure 3-7. 1 MW Single Axis Crystalline

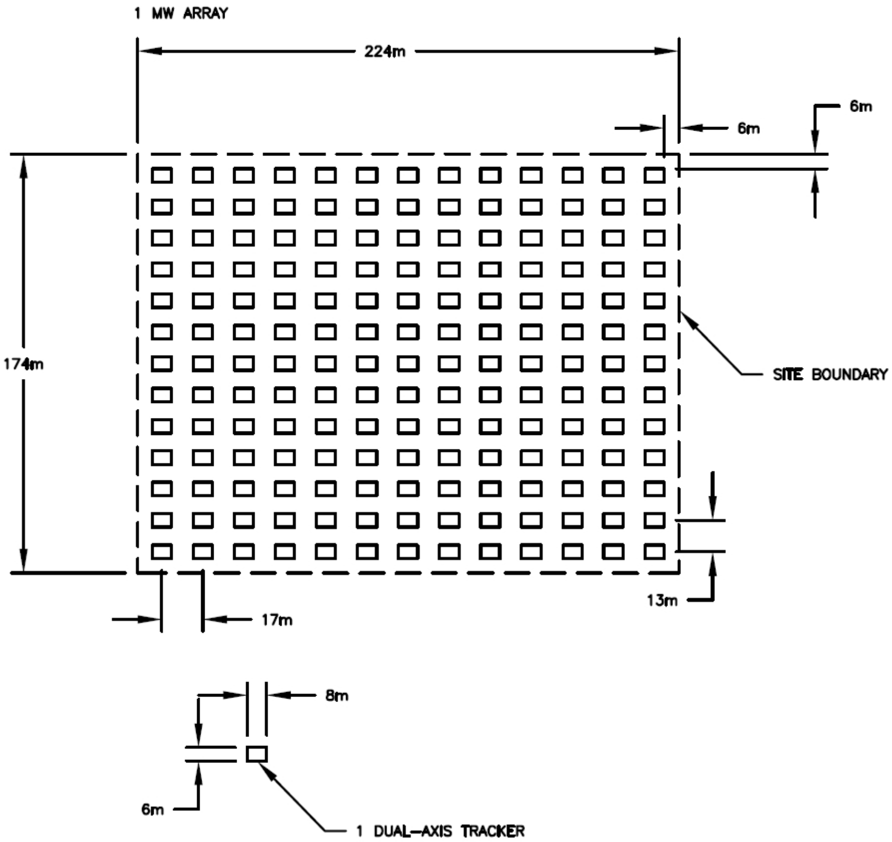


Figure 3-8. 1 MW Dual Axis Crystalline

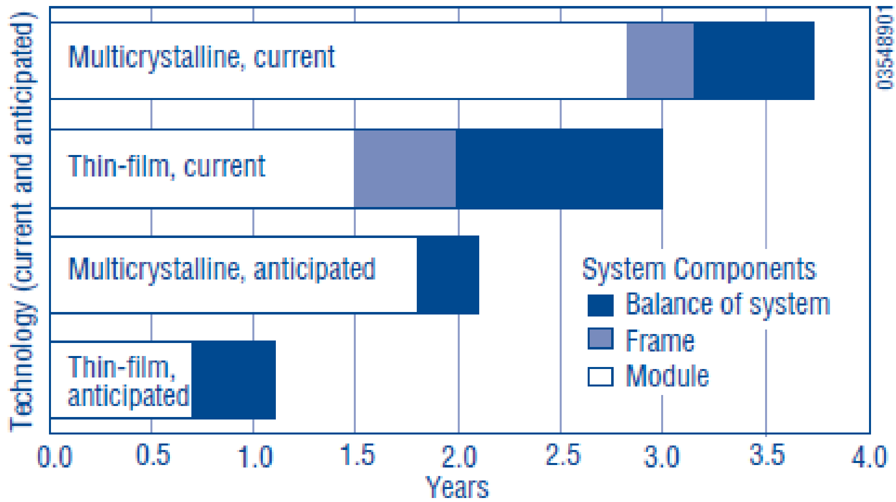
3.2 Operations and Maintenance

In comparison with other types of electrical power plants, PV plants require less maintenance and few, if any, on-site personnel. The inverters are the most critical components and they tend to be the cause of most major outages in a PV plant. However, inverter technology has improved significantly over the past few years. Modern inverters are now warranted for up to 20 years[3] and typical failures, if they occur, often happen during commissioning or very early in the life of the plant and are thus within the warranty period. Besides scheduled maintenance for inverters and transformers, the other activities include periodic washing of the modules and unscheduled maintenance activities, which require minimal staffing. Utility scale projects sometimes maintain one or two operators on-site to provide support if needed. With the use of sophisticated control and communications electronic equipment, PV plants are in the process of being automated enabling remote control of the facilities. Monitoring of systems is already often done remotely.

There are no emissions associated with solar PV systems during operations. However, a substantial amount of energy is consumed in producing modules and associated balance of system components. According to analysis commissioned by the U.S. National Renewable Energy Lab (NREL), the energy payback period for the energy consumed in manufacturing solar cells and accompanying components are show in the table below.[4] Current production technologies for PV systems have about 3-4 years energy payback, while future production technologies have goals to achieve 1-2 years energy payback

[3] Extended warranties, standard warranties are between 5 to 10 years.
[4] "PV FAQs," NREL. 2009.

periods. Considering the life of solar panels is anticipated to be 20-25 years, the energy input using today's technology is about 15% of the lifetime output.



Reaping the environmental benefits of solar energy requires spending energy to make the PV system. But as this graphic shows, the investment is small. Assuming 30-year system life, PV systems will provide a net gain of 26 to 29 years of pollution-free and greenhouse-gas-free electrical generation.

Figure 3-9. Energy Payback for Rooftop PV Systems (NREL 2009).

3.3 Project Summary

Table 3-1 and Table 3-2 summarizes cost and land use characteristics of typical solar PV projects in Ukraine. For larger projects (>20 MW), the amount of land that is needed would be equivalent to smaller farms in Ukraine. There are some proposed projects that are 100 MW in size and could occupy up to 250 – 450 hectares of contiguous land.

Table 3-1. Typical Project Land Usage.

	(ha/MW)	1-5 MW System (ha)	5-20 MW System (ha)	20+ MW System (ha)
Crystalline Fixed Tilt	2.6	3-13	13-52	>52
Thin-Film Fixed Tilt	4.5	5-23	23-90	>90
Crystalline Single Axis Tracking	2.8	3-16	16-64	>64
Crystalline 2-axis Tracking	2.8	4-19	19-76	>76

Table 3-2. Typical Project Costs.

	Installed Costs ($/kWp)			
	1-5 MW System	**5-20 MW System**	**20+ MW System**	**O&M Costs ($/kWp)**
Crystalline Fixed Tilt	4900-5400	3700-4200	2900-3400	30-40
Thin-Film Fixed Tilt	4700-5200	3500-4000	2800-3300	30-40
Crystalline Single Axis Tracking	5900-6400	4700-5200	3700-4200	50-60
Crystalline 2-axis Tracking	6500-7000	5000-5500	4300-4800	50-60

(a) Interconnection and Transmission

- Solar PV plants consist of DC solar panels tied together as a grid into a DC-to-AC inverter. Inverters provide negligible single line to ground fault current to the system. Inverters do increase harmonic content to a system due to the power electronics required to convert the power to AC. Increasing harmonic content can create stability concerns for an interconnection, especially within weaker power systems (e.g. radial distribution lines). Although there is a small amount of fault current contributed by the inverters, the padmount transformers and cable can still provide a source of fault current, albeit low in contrast to other technologies. Different padmount transformer configurations can also increase or decrease the amount of fault current onto the system, so it is important to design the system to keep the zero sequence impedance to a minimum, but still have a ground reference (so no overvoltage scenarios occur). Series neutral reactors or resistors can be added to the neutral connections of the collection system to increase the zero sequence impedance, thus decreasing the fault current. Solar PV projects of different sizes have different interconnection concerns as discussed below. **Smaller scale solar interconnections (1-5 MW)** are typically more feasible to interconnect at lower voltages due to the equipment necessary to build out an interconnection substation for the solar plant. These interconnections would be best suited at the distribution levels. Solar facilities of this size tend to serve local load instead of delivering power across long transmission lines. The only caveat is that intermittent resources should not be interconnected to radial distribution systems due to stability concerns.

  Smaller scale solar plants can typically deliver the power through one medium voltage underground feeder which may tap into the distribution system at an interconnection substation. The solar panels and inverters are located inside the solar plant substation along with the inverters and step-up transformers. The inverters from each solar array will connect together at approximately 480 V and then require a low voltage to medium voltage step-up transformer to deliver the power to the distribution tap. Some newer inverter models have built-in transformers that step up the voltage to the distribution level.

- **Medium scale interconnections (5-20 MW)** are typically more feasible to interconnect at the distribution voltages or lower transmission voltages, such as 220 kV and 330 kV. These substations require more inverters, more feeders, and larger equipment. These solar plants may serve local load, but can also be delivered into key transmission substations which step up to higher voltages. It is also optimal to locate these at substations with multiple outlets to avoid curtailment and ensure delivery of power.

Medium scale solar installations typically require more feeders from the inverters, but once collected together can be combined to step up the voltage through a step up transformer. Some inverters have transformers built in, and in this case, would just need to be connected into enclosed switchgear within a new collector substation which then is connected via overhead transmission to an interconnection substation. The switchgear may also be located within an existing substation and interconnected to a built-out bus within the fence.

- **Large scale solar interconnections** (> 20 MW) are typically injected at higher voltage substations with multiple outlets to deliver the transmission. The reason for this is to allow for delivery dispersed between multiple transmission lines and to avoid curtailment. Large scale solar plants collect into a large collector substation with switchgear after the inverter. Newer inverters with transformers built in can deliver the power at distribution voltages, but this would still need to be stepped up again to get to the transmission voltage. These built-in transformers may not benefit the overall installation of the solar plant due to the large quantity of feeders necessary. The switchgear delivers the medium voltage feeders (approximately 25 MW per feeder, up to eight feeders per enclosed switchgear) to one or more step up transformers. This power is then delivered to the interconnection substation or an existing substation with space to build out the bus work for future expansion. This process usually includes reconfiguration of the existing substation with a ring bus or breaker and a half scheme.

(b) Availability of Components in Ukraine

In order to qualify for the Green Tariff from 2012 onwards, renewable energy facilities must contain at least 30% of raw materials, supplies, fixed assets, works and services (engineering, construction) of Ukrainian origin (or “Ukraine content provision”) in the cost of construction. The content requirement increases to 50% by 2014.

Ukraine historically produced photovoltaic panels for the Soviet space programme. JSK "Kvazar”, the largest silicon and solar manufacturer in Ukraine, has been engaged in the development and manufacturing of PV production since 2001. According to the company, their current annual production capacity is 12 MW of solar cells, including monocrystalline and multi-crystalline cells.[5] The company is vertically integrated with a full range of PV products, from silicon (8% of world silicon production), wafers, cells & modules to complete PV systems. As there has been a limited market for photovoltaic products in Ukraine, almost all of the panels were exported elsewhere in Europe. For the project sizes being proposed, this manufacturer would need to increase production capacity significantly to meet that demand.

While the modern inverters that use advance technology for extended life and higher conversion efficiency may need to be imported, Ukraine may be equipped with the technology infrastructure to develop and manufacture its own inverters for PV applications. Racking systems and construction labor can utilize domestic resources.

3.4 Site Considerations

A variety of issues need to be considered when selecting a site for the development of a PV facility. Of primary consideration is the quality of the solar resource available on site. Although PV equipment can be designed to accommodate steep sites, it is more economical to develop areas that have slopes below 5%. Other site characteristics that will affect the technical and economic viability of the project include site accessibility for construction and maintenance activities and the proximity of the site to transmission lines and load centers.

[5] http://www.kvazar.com/cells.php. Accessed February 13, 2011.

Land usage is fairly intensive for PV facilities and generally speaking there is little or no opportunity to have dual usage for the land; therefore alternative land uses (for example, agricultural) must be considered when selecting an appropriate site.

There will be visual impacts but PV facilities are generally low profile and are not visible from far away. There will be little or no noise or odor impacts on the local community during operations so this will not likely affect site selection to a great extent. For solar PV, water consumption is low and therefore proximity to a water supply is not a requirement for site selection.

3.5 Construction Activities

The components and activities required for construction are dependent on both the technology and the location. However, construction of any solar energy development project is likely to involve the following major actions:

- establishing site access
- performing site grading
- constructing laydown areas and an on-site road system
- removing vegetation from the solar field, construction, and laydown areas (primarily for fire safety)
- constructing the solar field
- central control building
- a weatherproof area for minor maintenance and for storage of equipment and parts (which may be separate or combined with the control building)
- electrical substations
- meteorological stations (if not done during site characterization)

Additional activities may also be necessary at some facilities, including, constructing sanitary facilities, temporary offices, and landscaping. Construction would generally be divided into two phases, which would include a site preparation phase of relatively short duration (e.g., a few months) followed by a longer assembly, testing, and start-up phase, depending on the planned capacity of the plant. For example, a 30 MW PV plant could be completed in 15 weeks with 3 crews working in parallel (10 MW blocks each), excluding commissioning.

FIGURES

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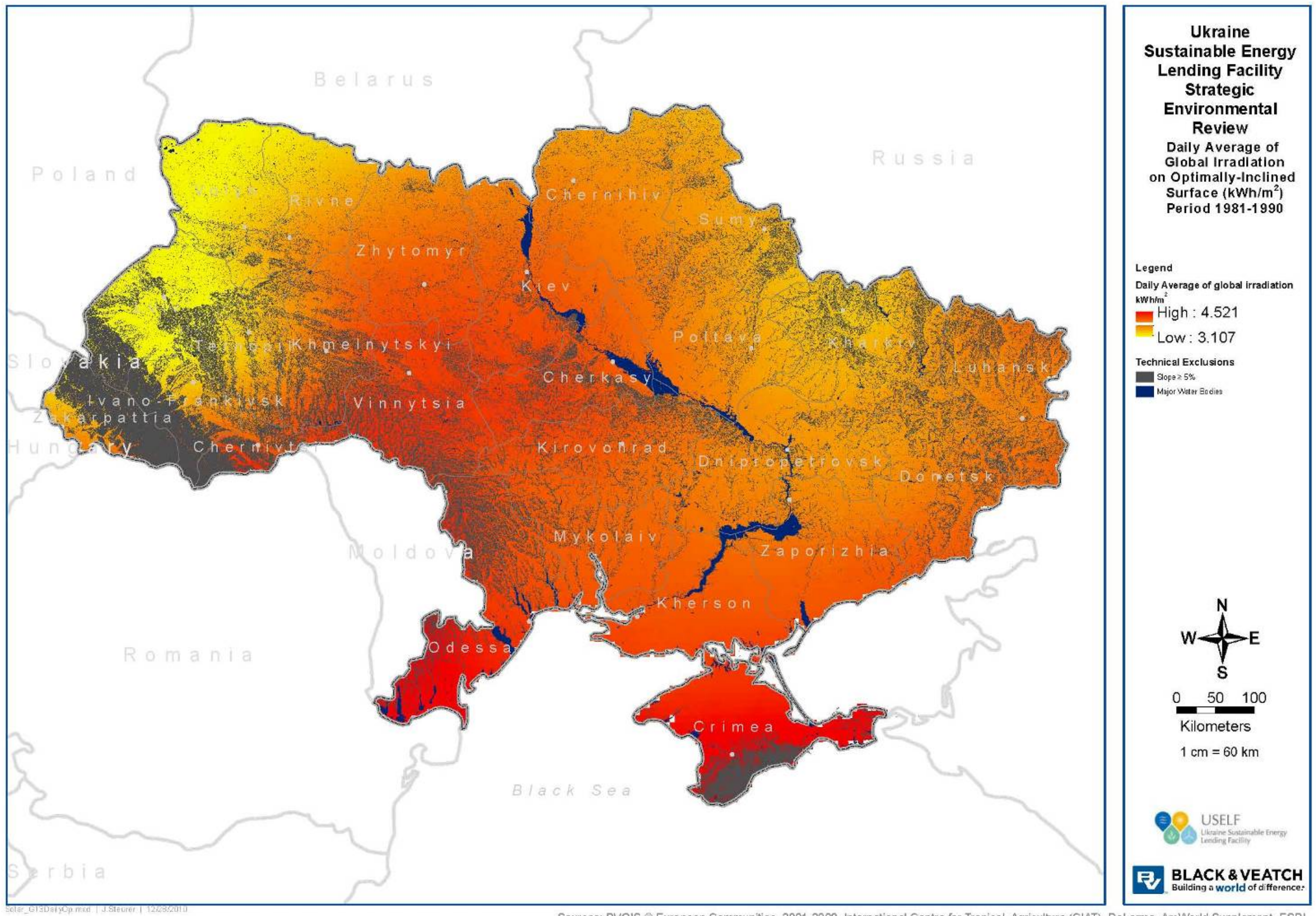

Sources: PVGIS © European Communities, 2001-2008, International Centre for Tropical Agriculture (CIAT), DeLorme, ArcWorld Supplement, ESRI.

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