Presented at the 33rd European PV Solar Energy Conference and Exhibition, 24-29 September 2017, Amsterdam, Netherlands

TECHNICAL AND ECONOMIC POTENTIAL OF PV IN LEBANON AND JORDAN AIMING FOR REGIONAL READINESS LEVEL DEVELOPMENT

M. Haidar[1,2] P. Baliozian[1], A. Mustafa[2], S. Mourad[2], and R. Preu[1]
[1] Fraunhofer Institute for Solar Energy Systems (ISE), Heidenhofstraße 2, 79110 Freiburg, Germany
[2]Albert-Ludwigs-Universität Freiburg, Zentrum für Erneuerbare Energien (ZEE), Tennenbacher Straße 4, 79106 Freiburg, Germany
Contact email: mohamad.haidar@ise.fraunhofer.de

ABSTRACT:
This paper provides an approach to calculate the technical and economic potential for photovoltaic (PV) power generation in Lebanon and Jordan as an initial attempt to regionally quantify energy. The technical potential was estimated using analytical and *GIS* (*Geographic Information System*) based methods having sets of constraints and assumptions. Moreover, the economic potential is also estimated using *GIS*. The results of this study indicate a calculated technical potential with a total of 21330 TWh/a in both Lebanon and Jordan compared to the analytically calculated technical potential of 20941 TWh/a. As for the economically feasible energy production, the expected total electricity production is 596 TWh/a. The *GIS* method provides a regional visualization of the potentials on the map showing regions with high and low potentials. Having projects in the PV sector can clearly cover a significant share of the demand, knowing that the economic potential in this approach shows an energy production with an order of magnitude higher than the total electricity demand of 26.7 TWh/a. The concepts of technology readiness level (TRL) together with the results obtained from the study motivate the introduction of a new concept in standardizing PV installed capacity maturities called Regional Readiness Levels (*RRL*). The *RRL* notion ranks regions according to parameters based on market potential of PV, aiming to overcome communication barriers within the PV community.
Keywords: Photovoltaic, technical potential, economic potential, GIS, Regional Readiness Level

1 INTRODUCTION

With today's environmental challenges and increasing energy demand, renewable energies have become inevitable to secure a sustainable future. Photovoltaic (PV) based solar energy conversion systems play a significant role in the clean energy transition. Today, solar PV installations worldwide exceed 300GW[1]. According to the International Technology Roadmap for Photovoltaics, the installed PV capacity is expected to increase in a logistic growth curve, reaching a yearly annual growth of 70 GW_p [2]. The aggregate penetration of photovoltaic electricity in the energy market requires technological advancements achieving higher efficiencies coupled with decreasing costs, along with progress in careful resource planning.

The main driver of PV systems' power generation is the solar irradiation that varies by a factor of four from a location to another on earth's surface [3]. Meaning that regional studies are necessary to estimate resources and study the technical and economic feasibility as an effort towards creating market targeting incentives.
Lebanon and Jordan are the countries that witnessed a high flux of refugees due to the Syrian war that started in 2011, reaching around 1.7 million refugees [4]. It is overt that a sudden increase of population requires a positive response in increasing electricity production to cover the increase of demand, especially if the population of the host country is of the same order of magnitude. Additionally, Lebanon's electricity infrastructure was severely damaged in the civil war (1975-1990) and was never properly reconstructed for many reasons. The electricity demand exceeds the supply, and Lebanese residents are subjected to daily blackouts reaching 13 hr/day [5]. The availability of solar energy, growth of the PV sector and the urgent need of electricity generation directs the focus towards this particular region.

The overall aim of this research paper is to assess the PV situation in Lebanon and Jordan, and calculate the technical and economic potentials of PV power generation within the vicinity of the two countries as a region of interest. In addition to that, a PV Regional Readiness Level (RRL) is introduced, with an approach of placing regions in a scale of PV market maturity. This study not only calculates an approximate PV electricity potential of Lebanon and Jordan; it also approaches the topic of standardizing regional PV installation maturities in RRLs as a possible method of establishing a common language within the PV community. In section 2, a brief description of the electricity production in the two countries Lebanon and Jordan is portrayed. Section 3 defines the PV potentials, and narrows down to the method of calculation used in obtaining the technical and economic potential of the region. In section 4, the results of the calculations are shown in addition to the introduction of the Regional Readiness Level table. The methodology used is illustrated in figure 1 below.

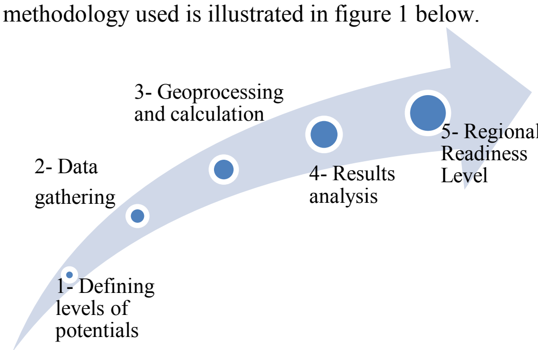

Figure 1: Flow chart describing methodology used in this work.

2 CURRENT ELECTRICITY PRODUCTION OVERVIEW

2.1 Lebanese electricity production

The main supplier of electricity in Lebanon is Electricity of Lebanon (*EDL*), which is a public institution linked to the Ministry of Energy and Water. *EDL* covers around 67 % of the electricity demand, leaving the rest for the households to manage. Two electricity bills are then paid, one for *EDL* and another expensive one for the private diesel generator owners that provide the back-up self-generated electricity during *EDL*'s blackouts.

In 2015, around 94% of *EDL*'s produced electricity was fossil fuel based, leaving around less than 6% to hydropower and imports. Solar PV electricity generation provides around 0.11% of *EDL*'s electricity generation, around 0.014 TWh out of the total 12.41 TWh of electricity generated [6]. Lebanon's official renewable energy target is attaining 12% renewable electricity and heat generation by 2030 [7]. The electricity generation and distribution sector in Lebanon needs to improve both in covering the demand as well as increasing the share of PV to meet the target. The Lebanese government recently approved plans to implement 180 MW of solar PV by 2020[8].

2.2 Jordanian electricity production

The Jordanian power sector is now regulated by the Electricity Regulatory Committee (*ERC*). The generation companies include the privately-owned and state-owned Electric Power Generating Company. The electricity generated from generators is sold to the state-owned National Electric Power Company (*NEPCO*) which operates the transmission systems. The electricity is then distributed to consumers through three privately-owned distribution companies [9]. 99.9% of the population has access to landline electricity. The total nominal capacity of the generation system is about 3,300 MW.

Jordan is heavily dependent on the import of foreign energy resources with 96% of its energy resources have to be imported. In 2012, around 14.3 TWh of electricity was consumed in Jordan, with a steady increase of around 5% per year over recent years [10]. Jordan has an official target of covering 10% of its primary energy demand using renewables by 2020 [7]. To meet its targets, the Jordanian energy sector has already implemented 77 MW of solar PV with another 540 MW currently under execution and 200 MW to be awarded in 2017. [11]

3 THE PV POTENTIALS, CALCULTION METHODS AND ASSUMPTIONS

3.1 Defining the potentials of PV

Different sources of renewable energy present different opportunities for utilization. It is then necessary to evaluate and assess the opportunities or potential presented by each one of them. Combining different sets of information, assumptions and constraints will yield different levels of potential. Lopez *et al.* define four main levels of potential. These levels are built upon each other, providing a clearer and more comprehensive understanding of the potential presented by a given source of renewable energy [12]. A quick overview of the different levels of potential is shown below in Figure 1.

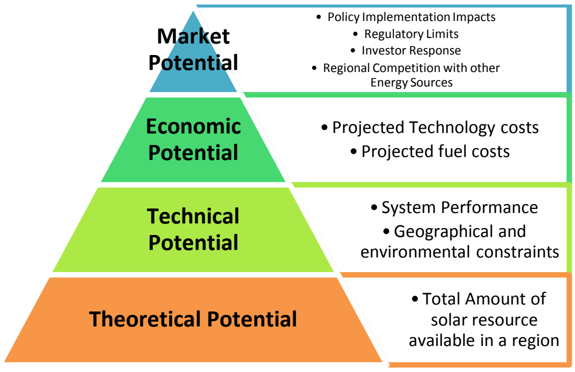

Figure 2: Different levels of potential as defined by Lopez *et al.*, adapted from [12].

3.2 Assumptions and calculation method of the PV potentials in Lebanon and Jordan

After defining the different potentials of PV system installations, Lebanon and Jordan are chosen as a region of interest for the potential study. The *Yingli* YL 260 W multi-crystalline solar panel is a common module used in Jordan. [13] It was selected for the study as standard module with an efficiency of 16%.

Analytical calculations using equations 1 and 2 and a set of assumption and givens from references:

$$\boldsymbol{RP = A_{total} * G_{avg}} \qquad (1)$$

RP: resource potential in GWh/a

A_{total}: total area of country or region of interest in km^2

G_{avg}: Yearly average Global Horizontal Irradiation (GHI) for the country/region of interest in $\frac{kWh}{m^2}/a$

$$\boldsymbol{TP = A * G * \eta * PR} \qquad (2)$$

TP: Technical potential in GWh/a

A: Available land area is determined by land use constraints, km^2

- Exclude all forests and protected areas
- Exclude all agricultural areas (arable land and permanent crops)
- Exclude all water areas

G: Yearly average GHI for the constricted region of interest in $\frac{kWh}{m^2}/a$

η: Standard module efficiency is the module efficiency under standard testing conditions (Module Temperature T= 25°C, Irradiance G= 1000W/m^2)

PR: Performance Ratio as defined in [14].

Assumptions:

- All PV panels are installed horizontally
- Performance Ratio of PV system is 0.8 for both Lebanon and Jordan since in Jordan PRs were found to be around 0.82 for Amman and around 0.77 for Aqaba [10].

- Module efficiency of selected module is 0.16
- Only 10% of urban areas can be used for PV: 20% of roof space is considered to be available and only 50% of the rooftops suitable for PV installation. This is a conservative assumption; however it is very common in Lebanon and in Jordan to have water storage tanks on the roof, Heating Ventilation and Air conditioning (HVAC) equipment and multiple satellite dishes.

As for the economic potential:

The levelized cost of PV electricity over 20 years varies depending on site, system price and operation and maintenance (O&M) costs. The table 1 below provides a comparison of PV and fossil based generation. The PV prices vary depending on system type, location, and O&M costs while fossil-based depends heavily on fossil fuel prices. Grid connected utility scale systems are cheaper and off-grid systems with battery storage are the most expensive [15]. Many PV systems have achieved grid parity and some systems are cheaper than fossil based electricity. Systems including storage remain more expensive. Therefore, the economic potential of PV is estimated to be at a penetration rate of 20-40% of total electricity demand. Above this penetration rate, PV will lose its economic value and become more expensive due to the requirement of storage caused by the intermittent nature of solar energy [16]. The fact that annual demand and annual solar irradiation curves follow the same pattern helps to allow a higher penetration rate due to direct consumption.

Table 1: LCoE of PV compared to fossil fuels

Country	Jordan	Lebanon
PV LCoE (EUR/kWh)	>0.057 [11]	0.046-0.485 [15]
Average cost of production and distribution from fossil fuels (EUR/kWh)	0.146 [10]	0.14 [5]

Geographic Information System (*GIS*) based calculation:

The calculation of the potential can also be computed and visualized on *GIS*. Visualizations might help policy makers pass more effective and region specific legislation. The original equation is modified in the following manner:

$$\boldsymbol{TP = A_{cell} * N_{cells} * G_{cell,Avg.} * \eta * PR} \qquad (3)$$

TP: technical potential in kWh/a
A_{cell}: Raster Cell Area in m^2
N_{cells}: Number of cells
$G_{cell,avg.}$: Average GHI/cell, calculated using Zonal Statistics in *GIS* once all exclusions and assumptions taken into account in $\frac{kWh}{m^2}/a$.

Excluded zones consist of:

- Zones with slopes higher than 5%
- Land used for Agriculture (Permanent Crop areas + Arable Land)
- Protected and Forest Areas
- Lakes and rivers
- Only 10% of Urban areas can be used for PV, urban areas are included regardless of slope. Other methods to identify available urban space as explained by Gagnon *et al.* in [17] require either unavailable light detection or ranging (LIDAR) sensor data or work intensive selection rendering them inapplicable for large areas.

The same formula can be used for the economic potential. Estimations can be made by adding the following assumptions and constraints to the study:

- Neglect PV module degradation rate and penetration rate constraint.
- Exclude all regions with below average radiation levels
- Exclude all regions not located within 15 km buffer radius of electrical substations
- Exclude all regions above 1500 meters in Altitude
- Include urban areas with a 1/3 ratio of urban technical potential: In other words, utility scale PV is more economic than residential/urban PV installations. [13][15].

The necessary data for the study was collected from different sources. Table 2 below is listing all data and sources:

Table 2: *GIS* data sources

Data Content	Data Type	Data Source
Urban Areas	Vector	Natural Earth
Water	Vector	Open Street Maps by GeoFabrik
Land use (Agriculture)	Vector	Open Street Maps by GeoFabrik
Protected Areas and Forests	Vector	WPDA consortium
Digital Elevation Model	Raster	ASTER Global DEM v2 from EarthData Nasa
Global Horizontal Irradiation	Raster	Solar-Med-Atlas
Direct Normal Irradiation	Raster	Solar-Med-Atlas

4 RESULTS AND DISCUSSION

The results are shown in table 3. The *GIS* processing produced the required results, visible in figures 3 to 5.

With the current state of technology and applying many geographical and environmental constraints, the technical potential obtained is huge for both countries. It is three orders of magnitude larger than demand for Lebanon and 4 for Jordan.

Table 3: Analytical results

Country	Unit	Lebanon	Jordan	Total	Ref.
Total Area	km^2	10452	89342	99794	[20] [21]
G_{avg}	$kWh/m^2/a$	1900	2100	-	[18] [19]
RP	TWh/a	19858	187618	207476	-
Land area	km^2	10230	88802	-	[20] [21]
Forest area	%area	13	1.1	-	[20] [21]
Agricultural land	%area	25	11.4	-	[20] [21]
Built-up area	%area	23.3	4.5	-	[20] [21]
$TP_{analytic}$	TWh/a	1021	19919	20941	-
TP_{GIS}	TWh/a	730	20600	21330	GIS
EP_{GIS}	TWh/a	518	78	596	GIS

The *GIS* technical potential of both Lebanon and Jordan returned similar results to the analytical estimation. As for Lebanon, the technical potential is lower than the analytically derived one. This is mainly because many highly sloped areas were excluded during *GIS* processing. Lebanon has large mountainous regions that can explain this exclusion. The variations can also be explained by the fact that, each time an area is excluded a new average for GHI has to be calculated which is done in the GIS but not in the analytic calculations.

The estimated economic potential is very high, considering the assumptions taken. In fact, it is 36 times demand for Jordan and 6 times for Lebanon. However the real economic potential would be at a penetration rate of around 20% to 40% as discussed above. Therefore, the current methodology does not attempt to project the level of PV generation that might be deployed in the future, but rather as a tool to identify the regions where PV projects are economically feasible and interesting. More advanced economic studies can be done using LCoE, which would require unavailable detailed country wide project costs data. Such studies exist on a regional European level as shown in Ossenbrink *et al.* [22]. The current analysis can be further refined to select the most economic locations enough to meet a certain PV penetration rate. A first approximation or judgement is that the central part of Jordan is best suited for PV as it is not far away from the demand and has very high economic potential. For Lebanon, the eastern region known as the Beqaa valley is suited for economic PV generation

A political and social analysis will further decrease the potential. However, it is very hard to define constraints to analyze this potential analytically or using *GIS*. That is where the concept of RRL becomes helpful.

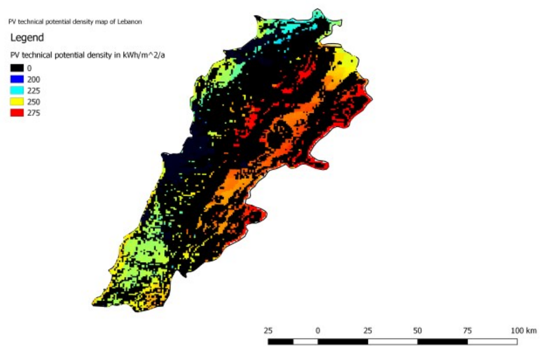

Figure 3: PV technical potential of Lebanon as estimated using the implemented methodology.

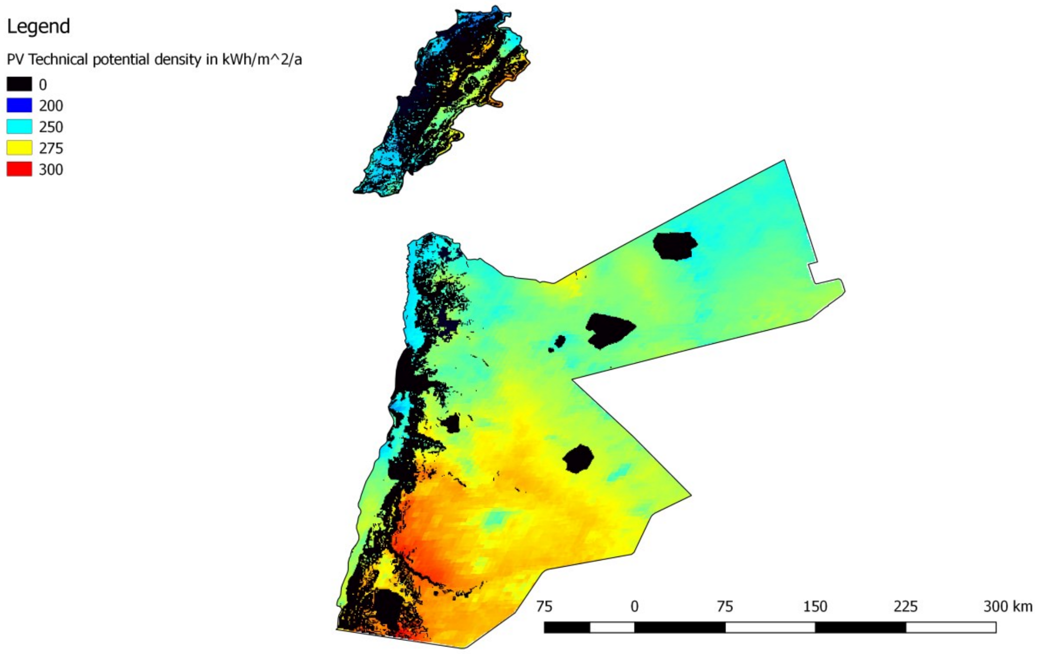

Figure 4: PV technical potential of Lebanon and Jordan as estimated using the implemented methodology.

5 REGIONAL READINESS LEVELS

A comparison of this assessment to other similar studies is difficult since different methodologies, definitions and assumptions are used. The idea of an RRL or country readiness level comes from the Technology Readiness Level *NASA Goddard Space Flight center* first proposed in the 1970s as a method to scale technology maturity from the concept observation stage to space flight readiness maturity [23]. A scale of 9 levels was created to rate the different maturities on a checklist format. The *European Commission* within the *Horizon 2020* program adopted such an approach to create 9-level TRLs as well as 10-level Manufacturing Readiness Levels (*MRLs*) [24]. Moreover, *Fraunhofer ISE* created a 10-level TRL stages table for PV cell production maturity [25].

The ambitious goal of *RRLs* differs from the previous concepts by assessing the readiness of implementing PV in a certain country instead of assessing a specific technology readiness/development. The RRL will characterize the maturity of a specific region by considering technical, economic and socio-political aspects, thus aiming for a standardized simplified language of discussion among renewable energy stakeholders. The RRL in table 4 below begins from conceptual aspects of PV planning to project execution to mass deployment, including the different sides in a single simple scale. The RRL is to be updated yearly.

Having a Regional Readiness Level scale provides a standard way of placing regions in levels of PV market maturity. In other words, it provides a qualitative and quantitative overview of the actual development stage in the PV market depending on parameters affecting such a development. The following table is a suggestion of such a scale. A more detailed RRL table can be created by including additional relevant factors affecting the advancement of PV in a specific region. After having a holistic scale agreed upon in the PV community, regions such as EU, Lebanon and Jordan could be marked

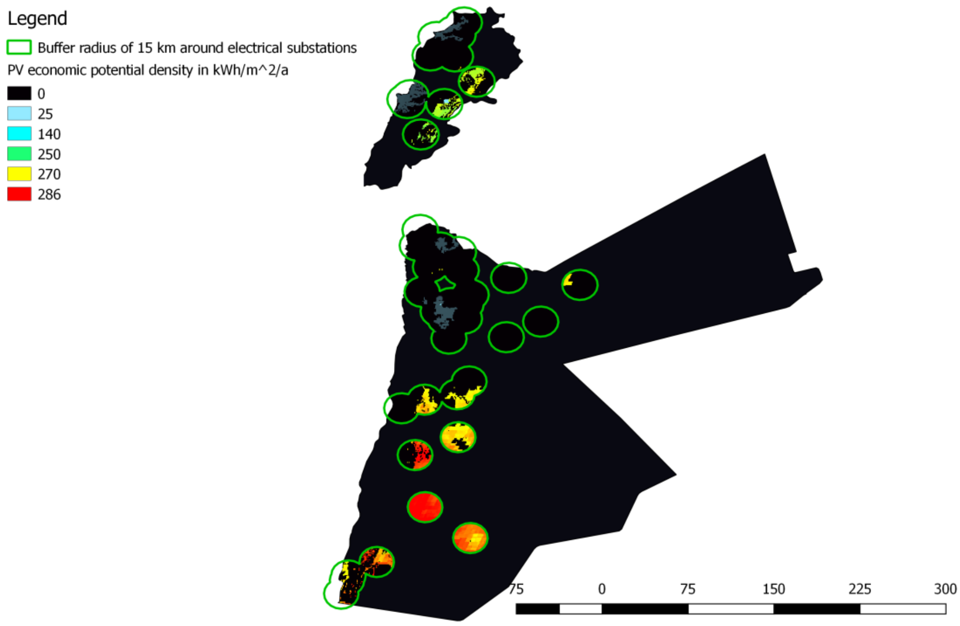

Figure 5: Economic Potential of PV for Lebanon and Jordan as estimated using current methodology

according to their respective RRLs. If the notion of RRLs develops to a future PV project standard, it would be a keyword used by scientists, engineers, investors and policy makers, thus closing the communication gap between these stakeholders.

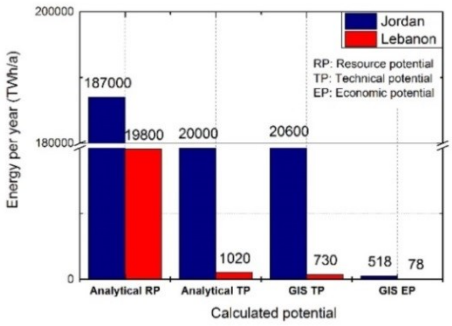

Figure 6: Results for the different calculated PV potentials in Lebanon and Jordan

Table 4: Regional Readiness Levels for PV

RRL0	• Basic Resource Potentials Observed • Official PV target exists
RRL1	• PV energy action plan • Market entry mechanism defined (1st come 1st served, tenders….)
RRL2	• Legal Framework for Renewables exists • Financial and regulatory incentives (Feed-in tariffs, tax reductions)
RRL3	• Institution responsible for tracking PV progress exists • Forecast for PV installation exists • Project subject to milestones or development timelines
RRL4	• Project mobilization and tracking through above mentioned milestones • Infrastructure proved to withstand PV installation
RRL5	• Local Manufacturing of PV
RRL6	• Peak shaving of electricity demand by PV in some areas at certain times
RRL7	• Peak shaving of electricity demand by PV in several areas for most of the time
RRL8	• Significant amount of electrical energy of the regional demand is supplied by PV
RRL9	• PV is a dominating source to supply the regions electrical demand

Lebanon can be placed currently at the RRL level of 2 based on the above overview of its electricity sector, since new plans have been announced. Policy makers in Lebanon would have to offer investors more incentives and plan ahead as well. Jordan is more advanced, with an RRL level of 6, since local manufacturing exists and the amount of PV currently operational allows peak shaving in some areas at certain times [26]. Germany is placed at an RRL level of 8, since PV currently represents a significant portion of the energy supply. [27]

The RRL is then a good tool to guide policy towards changes that will be beneficial for proper implementation of PV.

6 CONCLUSION AND OUTLOOK

In conclusion, Lebanon and Jordan have shown a high technical and economic potential compared to demand. Jordan has the larger potential between the two countries. The assumption based *GIS* study enables us to visualize the different potentials on a regional level. This can be beneficial for different stakeholders.

Developing a regional readiness scale simplifies the analysis even further for these stakeholders and presents the results in a unified standard format, hence closing the gap between the stakeholders during discussions. The concept of RRL is therefore introduced in this paper. Such a scale helps to compare the PV capabilities of different countries on a regional level and is an important tool for policy makers to assess the current situation.

The accuracy of this study is limited to the accuracy of the *GIS* data. For more reliable studies, assumptions should be further reduced by different models, while constraints and parameters increased. The need for more reliable and sensor measured data is urgent as well. The RRL could be developed to incorporate more detailed factors affecting the PV installed capacity on a regional level. Regions like EU can be included and compared to Lebanon and Jordan.

7 ACKNOWLEDGEMENTS

The authors would like to thank Heinz Ossenbrink for valuable input during the 32nd EUPVSEC session he chaired, which shaped the idea behind this study. The authors would also like to thank Julian Fleischmann from the University of Freiburg, Rami Fakhoury, Reem Irany and Patil Mesrobian from the Lebanese Center for Energy Conservation (LCEC), for their valuable information and references.

8 REFERENCES

[1] J. Dobson, C. Schlufter, T. Knoblich, A. Stiehler, Longer Term Investments, Renewables, UBS, 2017

[2] VDMA (2017). International Technology Roadmap for Photovoltaics - www.*ITRPV*.net.

[3] Hoogwijk, Monique Maria (2004): On the global and regional potential of renewable energy sources.

[4] United Nations High Commissioner for Refugees (UNHCR). "UNHCR Syria Regional Refugee Response." UNHCR Syria Regional Refugee Response. N.p., n.d. Web. 18 Jan. 2017.

[5] Fardoun *et al.* (2012) Electricity of Lebanon: Problems and Recommendations, Energy Procedia 19 – (310-320).

[6] Solar PV Status Report for Lebanon (2016), UNDP, Ministry of Energy and Water.

[7] Pan-Arab Renewable Energy Strategy 2030 – Roadmap of Actions for Implementation. International Renewable Energy Agency (2014).

[8] Bellini, Emiliano. "Lebanon issues RfP for 180 MW of solar." Pv magazine International. N.p., 31 May 2017. Web. 07 June 2017.

[9] Åberg, Emma, *et al*. "Up-scaling Solar PV for Self-Consumption in the Jordanian Market." TO THE FUTURE (2014): 72.

[10] Enabling PV in the MENA Region The Emerging PV Market in Jordan, GIZ, 2014

[11] Middle East Solar Outlook 2017. Rep. Middle East Solar Industry Association, 2016. Web. 9 June 2017.

[12] Lopez *et a.l,* U.S. Renewable Energy Technical Potentials: A GIS Based Analysis, NREL, July 2012

[13] Jordan Solar Power. "P.V Solar Panel." P.V Solar Panel. N.p., n.d. Web. 23 Jan. 2017. <http://jordansolarpower.net/main/index.php/products/p-v-solar-panel>.

[14] Smets, Arno H. M., Klaus Jäger, Olindo Isabella, René ACMM Van Swaaij, and Miro Zeman. Solar energy: the physics and engineering of photovoltaic conversion, technologies and systems. Cambridge, England: UIT Cambridge Ltd., 2016. Web.

[15] El Khoury, Pierre, Memorandum Ref: M13-6-V 5, Lebanese Center for Energy Conservation (LCEC), 2016

[16] Brown *et al.* "Estimating Renewable Energy Economic Potential in the ...", NREL, n.d. Web. 23 Jan. 2017.

[17] Gagnon et al. "Rooftop Solar Photovoltaic Technical Potential in the ...", Technical Report NREL/TP-6A20-65298 NREL. N.p., Jan. 2016. Web. 18 Jan. 2017.

[18] GroundWork for the development of Renewable Energy Action Plan. Rep. Association Libanaise pour la maîtrise de l'énergie et pour l'environnement, Dec. 2015. Web. 9 June 2017.

[19] Etier, Issa, Anas Tarabsheh, and Mohamad Ababneh. "Analysis of Solar Radiation in Jordan." Jordan Journal of Mechanical and Industrial Engineering 4.6 (2010): 733-38. Web. 9 June 2017.

[20]"The World Factbook: LEBANON." Central Intelligence Agency. Central Intelligence Agency, 12 Jan. 2017. Web. 18 Jan. 2017.

[21]"The World Factbook: JORDAN." Central Intelligence Agency. Central Intelligence Agency, 12 Jan. 2017. Web. 18 Jan. 2017.

[22] Ossenbrink *et al.* (2015), Towards a European Union of Photovoltaic Solar Electricity. 31st European Photovolatic Solar Energy Conference and Exhibition (EUPVSEC)

[23] Mankins, John C. "Technology readiness assessments: A retrospective." Acta Astronautica 65.9 (2009): 1216-1223.

[24] European Commission, Appendix G of Horizon 2020 – Work Program 2014-2015.

[25] Baliozian, P *et al.* (2016), Photovoltaic Development Standardizing Based on Roadmaps and Technology Readiness Levels (TRLs). 32nd European Photovoltaic Solar Energy Conference and Exhibition (EUPVSEC).

[26] "Why Philadelphia Solar?" Why Philadelphia Solar - Philadelphia Solar, philadelphia-solar.com/why-philadelphia-solar/. Accessed 3 Sept. 2017.

[27] Wirth, Harry, "Recent facts about photovoltaics in Germany", Fraunhofer ISE, n.d. Web 20 Sep 2017.