REPUBLIC OF LEBANON
MINISTRY OF ENVIRONMENT

ASSESSMENT OF PHOTOVOLTAIC PANEL

DEPLOYMENT IN LEBANON 2020 - 2023

& 2024 WAR DAMAGE EVALUATION

2025
LEBANON

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EXECUTIVE SUMMARY

This report presents a spatial assessment of photovoltaic (PV) panel deployment in Lebanon from 2020 to 2023 in addition to damages sustained due to the 2023-2024 war on Lebanon. It is a critical step towards evaluating Lebanon's progress in achieving its renewable energy goals outlined in the Nationally Determined Contributions (NDC), in line with 5/CMA.3 and 18/CMA.3 of the Paris Agreement. In the context of Lebanon's ongoing economic and energy crises, PV deployment has become a key element in alleviating energy shortages and in reducing reliance on fossil fuels.

This study leverages satellite remote sensing and Geographic Information System (GIS) techniques to map and analyze the distribution of ground and rooftop PV installations across Lebanon, providing crucial insights into their spatial distribution, their capacity, and the energy production of these systems. The study also assessed the damaged solar PV installations caused by the 2023-2024 war on Lebanon's South region and Beirut's southern suburbs.

By 2023, a cumulative minimum total of 241,298 PV units were mapped across Lebanon, covering a total average area of 6,858,399.70 m^2. The PV installations are distributed unevenly, with the highest concentrations in the Baalbek, Zahle, Saida, Baabda, and El Metn districts. Baalbek recorded the largest area of PV installations, with 638,324.52 m^2 of installed panels by 2023. Coastal districts also had a significant number of installations due to their higher population density and infrastructure availability. The year-on-year increase in installed PV area reflected a robust growth in solar adoption, particularly in response to Lebanon's energy crisis.

As a result, the installed PV capacity increased from 29.55 MWp in 2020 to 1,253.98 MWp by 2023. This capacity expansion led to a corresponding rise in energy production, from 84,448 MWh in 2021 to 1,793,824 MWh in 2023. The increase in average PV unit size also shifted over the years. In 2020, the average size of installed units amounted to 370.05 m^2 (reflecting large commercial installations). In 2022, a sharp decrease to 53.19 m^2 per unit was recorded mainly due to a shift towards smaller, distributed residential installations. A summary table of the resulting energy capacity and production is included below (Table i).

Table i: Growth of cumulative solar PV capacity and energy production in Lebanon (2020-2023)

Capacity-Energy / year	2020	2021	2022	2023
Cumulative capacity (MWp)	29.55	58.33	781.78	1,253.98
Cumulative energy (MWh)	42,272.79	83,447.85	1,118,349.4	1,793,824.37

Since October 2023, Lebanon has faced an intense war, causing widespread destruction, including damage to critical infrastructure including PV solar panel installations. This study assessed the impact of the war on Lebanon's solar energy sector using Sentinel-1 SAR data to detect structural damage. The assessment provided critical insights to guide post-war recovery efforts, prioritize energy restoration, and support Lebanon's renewable energy resilience. Key findings included:

- A total of 2,751 to 3,188 PV units were detected as damaged, accounting for 1.4 to 1.5 % of Lebanon's total PV area in 2023.

- This corresponds to an area ranging between 93,016 m^2 and 104,061 m^2, with the latter being approximately equivalent to 15 football fields.
- Districts with most affected PV panels included Baabda (i.e., mostly in the southern suburbs of Beirut), Baalbek, Sour, and El Nabatiyeh.
- The total loss was estimated to be between 14.9 MWp and 16.7 MWp in capacity. This translates to a loss of 21,289.62- 23,817.62 MWh in energy production, representing 1.2% to 1.3% of Lebanon's renewable energy production from PV panels in 2023, estimated at 1,793,824 MWh.

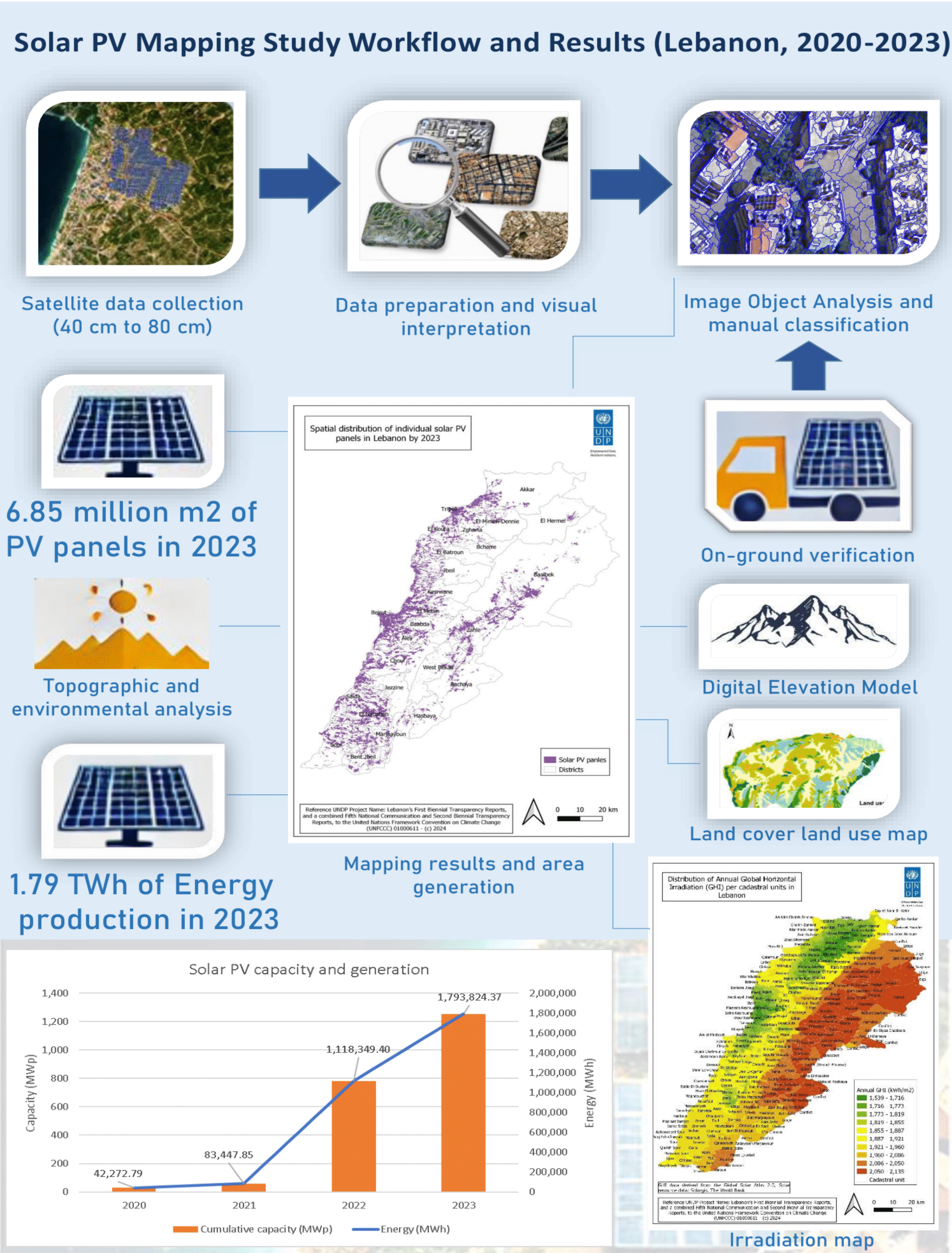
The mapping of PV installations was conducted using high-resolution satellite imagery, with a spatial resolution varying between 40 cm and 80 cm, covering the years 2020 to 2023. This resolution allowed for the detailed detection and delineation of installed PV panels, even in densely populated urban areas. In particular, online satellite imagery from multiple providers was used to cover all the Lebanese national territory. A grid-based approach, with an average of 100x100 meter cell, ensured no areas were overlooked. Any gaps from missing data were addressed through additional imagery or interpolation and extrapolation techniques. Every year, PV panels were delineated based on their geometric, spectral, and textural characteristics. The surface area of each mapped panel was calculated, accounting for panel inclination. The mapping results were validated through on-ground verification in a statistically significant sample of locations to ensure accuracy. The annual energy production from PV systems was calculated by accounting for the estimated capacity factor, solar panel efficiency, and the identified area of installed PV panels.

The topographic characterization of installed PV panels was conducted by overlaying the identified PV installations with a Digital Elevation Model (DEM) and land cover maps, alongside solar radiation data (i.e., the Global Horizontal Irradiation map from the World Bank Group's Global Solar Atlas). Most PV installations (over 3.99 million m^2 by 2023) were concentrated in elevations below 500 meters above sea level, predominantly in coastal cities resulting in an average capacity of 698.91 MWp. This concentration is likely due to population density and ease of installation. Installations at higher altitudes (above 1,500 meters) were minimal, reflecting challenges such as harsh weather and limited infrastructure and significantly lower population density. By 2023, approximately 540,587.5 m^2 of PV panels were installed on agricultural land resulting in an average capacity of 94.6 MWp, potentially supporting water pumps for irrigation. Another 446,557.9 m^2 was installed by 2023 in industrial zones, contributing to energy production with an average capacity of 78.15 MWp in high-demand areas. The Global Horizontal Irradiation (GHI) data revealed that districts such as Baalbek and Zahle, with GHI values exceeding 2,000 kWh/m^2, had the highest potential for solar energy generation. These regions are ideal for large-scale solar farms, with the report identifying 416,230 hectares of land at the national level in cadastral units with mean GHI above 2,000 kWh/m^2.

The accuracy of the solar PV mapping results was assessed using a confusion matrix, comparing classified data to reference ground-truth data. A total of 241,298 PV units were mapped, and 473 ground-truth sample points were analyzed, yielding a high overall mapping accuracy of 93.4%, with a producer's accuracy of 97.9% and a user's accuracy of 95.1%. Errors were minimal, with a 2.1% omission error and a 4.9% commission error. In addition, an uncertainty assessment of energy production was conducted, incorporating factors such as Capacity Factor (CF), kWp per square meter, inclination angle, and mapping accuracy. A Monte Carlo simulation was performed to account for these uncertainties, resulting in a mean energy production of 1,890,000 MWh (equivalent to 1,321.2 MWp), with a standard deviation of 300,000 MWh (equivalent to 209.7 MWp). The 95% confidence interval for total energy production ranged from 1,370,000 MWh (equivalent to 957.7 MWp) to 2,500,000 MWh (equivalent to 1,747.6 MWp).

Overall, Lebanon's rapid expansion of PV installations, despite economic challenges, represents a significant achievement in its renewable energy transition. By focusing on high-GHI regions and addressing infrastructure gaps, Lebanon can continue to enhance its solar energy capacity. Future efforts should target optimizing PV deployment in regions with high solar potential, while balancing land-use priorities and improving grid infrastructure to support further renewable energy growth. In addition, reports[1] indicate the start of the stagnation of PV installations, with the focus shifting towards donor-led and community-based solar projects; entities (household or otherwise) who could afford solar panels have already installed solar PVs. On the other hand, with the absence of any type of support, the remaining Lebanese entities cannot afford the cost of these installations, further exacerbating the disparity in existing inequalities among marginalized communities and low-income households.

[1] https://today.lorientlejour.com/article/1413635/experts-weigh-in-why-is-lebanons-solar-boom-no-longer-booming.html


Solar PV Mapping Study Workflow and Results (Lebanon, 2020-2023)
Satellite data collection (40 cm to 80 cm)
Data preparation and visual interpretation
Image Object Analysis and manual classification
On-ground verification
Digital Elevation Model
Land cover land use map
Irradiation map
Mapping results and area generation
6.85 million m2 of PV panels in 2023
Topographic and environmental analysis
1.79 TWh of Energy production in 2023
Spatial distribution of individual solar PV panels in Lebanon by 2023
Solar PV panles
Districts
Reference UNDP Project Name: Lebanon's First Biennial Transparency Reports, and a combined Fifth National Communication and Second Biennial Transparency Reports, to the United Nations Framework Convention on Climate Change (UNFCCC) 01000611 - (c) 2024
0 10 20 km
Distribution of Annual Global Horizontal Irradiation (GHI) per cadastral units in Lebanon
Annual GHI (kWh/m2)
1,539 - 1,716
1,716 - 1,773
1,773 - 1,819
1,819 - 1,855
1,855 - 1,887
1,887 - 1,921
1,921 - 1,960
1,960 - 2,006
2,006 - 2,050
2,050 - 2,135
Cadastral unit
Solar PV capacity and generation
Capacity (MWp)
Energy (MWh)
42,272.79
83,447.85
1,118,349.40
1,793,824.37
2020
2021
2022
2023
Cumulative capacity (MWp)
Energy (MWh)

ACRONYMS

BAU	Business-As-Usual
CF	Capacity Factor
DEM	Digital Elevation Model
DSM	Digital Surface Model
EDL	Électricité du Liban
GHI	Global Horizontal Irradiation
GIS	Geographic Information System
GSA	Global Solar Atlas
GW	Gigawatt
IRENA	International Renewable Energy Agency
KWp	Kilowatt-peak
LCEC	Lebanese Center for Energy Conservation
MWh	Megawatt-hour
MWp	Megawatt-peak
NDC	Nationally Determined Contribution
NEEREA	National Energy Efficiency and Renewable Energy Action
NREAP	National Renewable Energy Action Plan
PERC	Passivated Emitter and Rear Cell
PPES	Policy Paper for the Electricity Sector
PV	Photovoltaic
TWh	Terawatt-hour

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I. INTRODUCTION

In response to the call for enhanced commitment under Article 4.9 of the Paris Agreement and in alignment with Law 115/2019, Lebanon updated its 2015 Nationally Determined Contribution (NDC) in 2020. This move highlighted Lebanon's dedication to tackling the climate crisis through sustainable development, despite facing significant challenges such as its economic, financial, monetary, and banking crises, which have greatly impacted its economic performance, people's livelihoods, and overall growth and development.

Lebanon has pledged to increase its greenhouse gas emission reduction target unconditionally from 15% to 20% relative to the Business-As-Usual (BAU) scenario. Additionally, under its conditional target, Lebanon aims to increase this target to 31%. In line with these goals, Lebanon committed to generating 18% of its electricity demand and 11% of its heating demand from renewable energy sources by 2030, up from a combined 15% in 2015. Conditionally, these targets rise to 30% for electricity and 16.5% for heating by 2030, compared to a combined 20% in 2015, as guided by the Renewable Energy Outlook for Lebanon (IRENA, 2020).

Many of the proposed actions to meet these NDCs are included in approved ministerial strategies and plans, such as the 2019 Policy Paper for the Electricity Sector (PPES) and the 2020 International Renewable Energy Agency's (IRENA) Renewable Energy Outlook.

However, Lebanon has been grappling with a devastating conflict since October 2023, marked by intense military operations, airstrikes, and artillery shelling, primarily concentrated southern Beirut suburbs and in the southern and border regions. The war has caused significant destruction to infrastructure, natural ecosystems, and agricultural lands, posing severe humanitarian and environmental challenges. Among the critical infrastructures at risk are PV solar panel installations, which have witnessed a rapid expansion across Lebanon in recent years.

The objective of this work is to contribute to the assessment of Lebanon's progress in achieving its NDCs for renewable energy generation, specifically from photovoltaic (PV) electricity, to enhance the tracking and reporting of progress of the NDC implementation, in line with 5/CMA.3 and 18/CMA.3 of the Paris Agreement. This involves a comprehensive assessment of installed PV panels in Lebanon using satellite remote sensing techniques with very high spatial resolution satellite data from 2020 to 2023. The study also analyzed the damage caused by the 2023-2024 war on Lebanon to PV panels assessed during the 2020-2023 period especially in the most heavily affected areas.

With the number of solar power systems in Lebanon rapidly increasing over the past three years, there is a growing need for high quality, up-to-date information on the status of PV systems. However, access to this data is outdated, especially given that, since the beginning of 2021, the number of solar companies in Lebanon has surged from 130 well-established firms to over 400, many of which are not professional (Azhari, 2021).

In this context, innovative approaches such as using very high spatial resolution satellite data have become essential for detecting PV units. Specifically, this study utilized satellite remote sensing techniques to accurately map and analyze PV units installed on both rooftops and on the ground across the country. The employed methodologies involve several key steps, each contributing to a comprehensive understanding of the spatial distribution and area coverage of PV installations. PV panels were mapped based on their spectral, spatial, and textural characteristics. To determine the real flat area of the PV installations, the study accounted for the inclination of PV panels. The accuracy of the mapping and area calculations was validated against ground truth data.

In addition, the outbreak of war has raised serious concerns about the extent of damage inflicted on these PV panels, particularly in regions subjected to repeated bombings and artillery shelling. Unlike traditional infrastructure damage assessments, evaluating the destruction of PV panels is challenging due to their small footprint, dispersed locations, and the difficulty of on-site verification in conflict zones. Remote sensing techniques, particularly Synthetic Aperture Radar (SAR) from Sentinel-1, offer a robust alternative by allowing the detection of changes in surface reflectivity, structural damage, and debris accumulation without requiring direct visibility.

II. BACKGROUND

The Lebanese Republic, located on the eastern Mediterranean, covers an area of 10,452 km^2. Lebanon has a 225 km coastline along the Mediterranean Sea, with a coastal plain that stretches up to 6.5 km at its widest point. The country's mountains reach elevations of up to 3,088 meters. The Beqaa Valley, situated between the Lebanon and Anti-Lebanon Mountains (which have a peak elevation of 2,814 meters), acts as a natural divider in the country's varied landscape.

As of 2022, Lebanon's population is estimated at around 5.5 million with a decrease since 2019 due to the massive emigration trend instigated by the political and financial crisis – despite the influx of refugees from neighboring countries (World Bank, 2019a). Traditionally, Lebanon's economy has relied heavily on its service sector, focusing on banking, tourism, construction, and real estate, primarily driven by the private sector. Lebanon faced a severe economic and financial crisis, considered one of the worst since the mid-nineteenth century. Between 2018 and 2023, the GDP experienced a 67% drop per capita, effectively erasing over 22 years of development progress (World Bank, 2024). The crisis, compounded by the COVID-19 pandemic, Beirut Port explosion, and geopolitical tensions, has led to the collapse of public services, particularly the electricity sector, where power supply in some areas has dropped to less than an hour per day. This has significantly impacted poverty rates, equitable access to energy, and recovery prospects.

One major burden on the Lebanese economy is the cost of power generation. Electricité du Liban (EDL), the national electricity provider, reports deficits close to USD 2 billion. Lebanon struggles with compiling energy data and has yet to produce a complete energy balance. The primary energy production in Lebanon mainly comes from imported oil products, with fuel imports accounting for around 95% of overall energy production costs and imports in 2016 (IRENA, 2020).

The electricity sector and the ongoing economic crises are closely linked. Primarily relying on fossil fuels for power, and since the financial crisis began in 2019, the Lebanese government can no longer afford to import or subsidize fuel. This led to worsening power outages and a collapse of the power system in the summer of 2021. By the following year, households across the country faced long power cuts, with some regions experiencing blackouts for up to 23 hours a day (Sabaghi, 2022).

Initially, Lebanese households and businesses turned to expensive private diesel generators for electricity. The unregulated private diesel generator sector and poor air quality management further exacerbated pollution (Abdelkader et al., 2019). Historically, renewable energy in Lebanon was limited to biomass heating in rural areas and hydroelectric facilities built before the 1970s, which once accounted for over 75% of Lebanon's electricity generation. In 2015, the NDC set a goal for renewables to make up 20% of the country's electricity demand by 2030, a target reinforced in the 2019 electricity reform policy and increased in the NDC update in 2021 to 30%. Before 2019, the government aimed for renewables to constitute 12% of the total primary energy consumption by 2020.

Electricity consumption in Lebanon decreased by 29% between 2021 and 2022, while the contribution of renewable energy sources to the electricity generation mix increased significantly from 6.3% in 2021 to 20% in 2022 (MoEW/LCEC, 2023).

III. PV TRENDS AND DEVELOPMENTS

Lebanon benefits from an annual average solar irradiation ranging from 1,520 to 2,148 kWh/m^2/year, with most areas receiving over 1,900 kWh/m^2/year, as reported by IRENA's Global Atlas for Renewable Energy. Based on this solar irradiation data, IRENA estimates that Lebanon has the potential to achieve up to 182 GW of utility-scale solar PV capacity. This projection considers factors such as resource quality, access to transmission lines, topography, population density, protected areas, and land cover, unveiling that Lebanon has over 5,558 km^2 of land suitable for utility-scale solar PV projects. Assuming a land-use rate of 33 MW per km^2 for solar PV, this translates to a potential capacity of approximately 182,615 MW.

According to the Lebanese Center for Energy Conservation (MoEW/LCEC, 2022, 2023), several figures, trends, and developments were observed up to the year 2022 (Figure 1Figure 1 and Figure 2Figure 2):

- In 2020, Lebanon's EDL generated 12,500 Gigawatt-hours (GWh) of electricity.
- The installed capacity of decentralized solar PV increased from 0.3 MWp in 2010 to 869.3 MWp in 2022
- The year-on-year increase in cumulative installed capacity since 2010 illustrates this rapid growth.
- A total of 777 MWp of solar PV capacity was installed in 2021 and 2022, representing an 842% growth in cumulative installed capacity over just two years.
- The additional installed capacities of solar PV resulted in an increase in energy generation, rising from 0.1 TWh in 2020 to 1.3 TWh in 2022.
- Until 2020, Mount Lebanon led with 29.97 MWp (33%), followed by Beqaa with 23.84 MWp (27%) and Baalbek-Hermel with 10.4 MWp (12%).

With reference to a focused survey conducted within the context of this work in 2024 towards a total of 22 active solar energy companies in Lebanon, the average residential power threshold was estimated at 12 KWp with a maximum of 35 kWp and a minimum of 5 kWp. The most common threshold was estimated at 8 kWp.

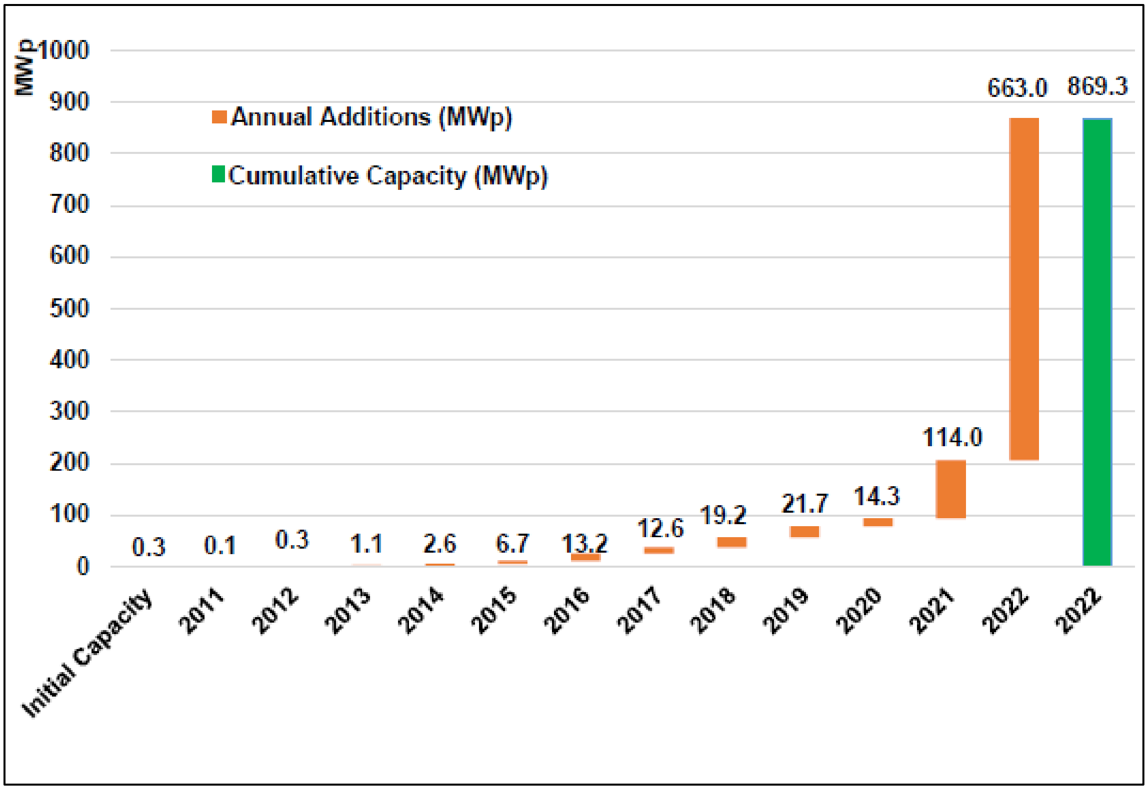

Figure 1: Annual additions and cumulative capacity of solar PV (MoEW/LCEC, 2023)

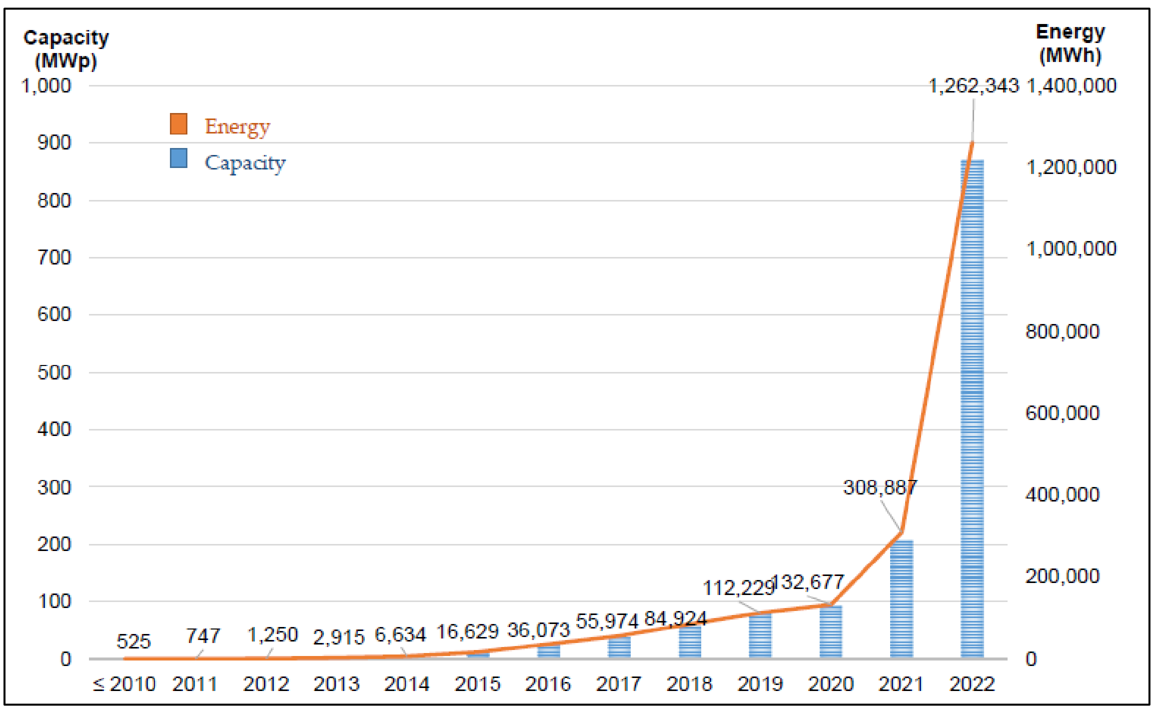

Figure 2: Solar PV installed capacity and energy generation (MoEW/LCEC, 2023)

The increasing trend of installed PV systems is closely linked to the reduction in costs due to several interconnected factors:

- **A rise in the cost of fossil fuels**: In 2021 and 2022, the rising cost of fossil fuels led to higher electricity bills in the parallel market, primarily driven by diesel generators, along with an increase in EDL's tariffs (post-subsidy removal). This situation sparked a surge in decentralized solar PV installations that began in 2021 and intensified in 2022. As a result, there was an urgent need for residents, industrialists, businesses, and healthcare providers to reduce their reliance on conventional power sources, especially diesel generators, and invest in off-grid or hybrid solar PV systems. From an end-user perspective, the average cost savings per kWh were $0.20 in 2021 and $0.60 in 2022, factoring in generator subscription costs, EDL supply, and the changes in EDL's kWh pricing in 2022. In terms of investments, Lebanon's solar PV sector had reached a total of $135.19 million by the end of 2020, despite the prevailing economic conditions. In particular, the total cumulative investment in the sector increased from $2.29 million in 2010 to $135.19 million in 2020, reflecting its significant economic potential. Between 2010 and 2020, the industrial sector led Lebanon's solar PV market with an installed capacity of 28.43 MWp (32%), followed by the commercial sector with 16.63 MWp (19%) and the agricultural sector with 15.57 MWp (17%).

- **Economies of scale**: With the global growth in demand for PV systems, production volumes have increased significantly. This has led to economies of scale, where the cost per unit of production decreases as the scale of production increases. Manufacturers are able to produce solar panels more efficiently, reducing the overall cost. In Lebanon, the turnkey price for solar PV installations dropped from $7,186 per kWp in 2011 to $807 in 2020, an 89% reduction over ten years, making solar PV technology more accessible and affordable (MoEW/LCEC, 2022).

- **Technological advancements**: Continuous research and development in the PV industry have led to improvements in technology. This includes better materials, more efficient production processes, and innovations such as bifacial panels and thin-film technologies. These advancements increase the efficiency of solar panels, allowing them to generate more electricity from the same amount of sunlight, thereby reducing the cost per watt of solar energy.

- **Supply chain optimization**: With the rising demand for PV systems, supply chains have become more efficient. Improved logistics streamlined manufacturing processes, and enhanced supply chain management have reduced the costs of raw materials and components, contributing to the overall decrease in costs.

- **Increased competition**: The growing market for solar energy has attracted many players, leading to increased competition among manufacturers. This competition drives prices down as companies strive to offer more cost-effective products to gain market share.

- **Government policies and incentives**: Many governments around the world have introduced policies and incentives to promote renewable energy, including subsidies, tax breaks, and grants for PV installations. These incentives reduce the initial cost for consumers, making solar energy more affordable and accelerating the adoption of PV systems. It was estimated that by 2020, 44% of the installed solar PV capacity was funded through the National Energy Efficiency and Renewable Energy Action (NEEREA) financing mechanism, amounting to $63.48 million, while 56% was funded by non-NEEREA investments, totaling $71.71 million (MoEW/LCEC, 2022).

- **Global supply chain and market expansion**: The expansion and technology advancement in the market for PV systems globally, especially in emerging markets, further drives down prices. Global market expansion also spreads the benefits of technological advancements and economies of scale across different regions, contributing to the overall reduction in costs.

As the prices for most distributed PV applications have dropped globally, hybrid systems, which are grid-connected with backup battery storage, now cost about USD 1,200 per kWp. Off-grid systems have seen the most significant price drop, nearly 46%, from over USD 5,000 per kWp in 2013 to around USD 3,000 in 2017. Grid-tied systems with battery backup have also seen a price reduction of 39%, from around USD 6,000 per kWp in 2013 to about USD 3,300 in 2017. These systems, along with solar pumping systems, tend to be more expensive due to the inclusion of battery storage.

The cost for grid-tied systems without battery storage has plummeted from USD 3,700 per kWp in 2013 to USD 1,400 in 2017, a reduction of almost 57%. Meanwhile, the price of solar PV pumping systems dropped by approximately 50% between 2014 and 2016, largely due to the growth in the number and scale of installations. It's important to note that these price figures, derived from NEEREA data, tend to be higher than typical market prices because they include financing and study costs.

As part of this assessment, a survey conducted among five different companies involved in the installation of PV panels, provided valuable insights into solar energy trends in Lebanon. During the peak installation years of 2022-2023, these companies averaged 150 systems per year, amounting to approximately 2,000 panels per provider annually. In 2020 and 2021, the COVID-19 pandemic and the resulting lockdowns significantly impacted the industry, leading to a surge in installations in 2022. While multiple factors contributed to this growth, the temporary reduction of import taxes on solar panels facilitated increased imports from China. However, it remains unclear whether this tax reduction significantly lowered costs for end-users, as service providers may have absorbed the savings to increase their profit margins. In reference to the same survey, the years 2022 and 2023 saw the highest number of panels installed. However, the frequency of installations decreased by the end of 2023 due to the reintroduction of import taxes on panels. In 2024, these providers are shifting their focus towards larger projects, rather than residential installations. The demand for solar energy has moved towards the industrial/commercial sector, with large solar units being installed across Lebanon.

IV. MAPPING PHOTOVOLTAIC PANELS

Data collection and verification

The first step involved identifying and accessing satellite imagery of Lebanon with a spatial resolution ranging between 40 cm and 80 cm covering the period from 2020 to 2023. This high-resolution data is available from various satellite imagery providers, online platforms (e.g. mostly Google Earth), open sources, and private companies such as Maxar Technologies, Bing Maps, and Planet Labs. An initial assessment confirmed that this resolution is suitable for the intended analysis. Appropriate access protocols were followed to obtain the necessary data.

Choosing a spatial resolution of satellite imagery ranging between 40 cm and 80 cm is a strategic decision that balances the need for detailed information with practical considerations such as data processing, cost and availability, and the specific characteristics of the detection task. More precisely, a resolution between 40 cm and 80 cm is detailed enough to capture small features on rooftops, such as PV panels and other rooftop installations. Furthermore, in dense urban areas, rooftops are often closely packed, and multiple structures may be in proximity. A 40 to 80 cm resolution is generally good enough to differentiate between rooftop installations on adjacent buildings, reducing the risk of misclassification or the merging of features that are close together.

In dense urban areas, closely spaced buildings and PV systems require sufficient spatial resolution for accurate differentiation. A study by Malof et al. (2016) demonstrated that spatial resolutions of 40 to 80 cm are sufficient to distinguish individual rooftop installations on adjacent buildings, reducing misclassification risks. This is crucial in urban settings, where rooftops often contain a mix of structures and equipment.

Numerous studies have used satellite imagery with 40 to 80 cm resolution and sometimes a slightly higher resolution for rooftop solar PV detection. For instance, Liu et al. (2023) utilized high-resolution satellite imagery to estimate rooftop PV potential in Beijing. Their study demonstrated the effectiveness of object-based image classification, combined with digital surface models (DSM), to accurately map rooftop PV systems and calculate potential energy generation.

Overall, 40 to 80 cm resolution imagery strikes a balance by maintaining high detection accuracy, (above 85%) while reducing computational demands, making it ideal for large-scale projects involving rooftop PV mapping.

Mapping methodology

A comprehensive analysis framework was developed to ensure that the selected imagery encompasses all the regions of the country. This framework involved creating an average 100m x 100m grid or overlay on a map of Lebanon to ensure no area is overlooked (Figure 3). Any geographical gaps or areas with insufficient detail were identified and additional imagery were arranged when needed. This step ensured that all the regions in Lebanon were included in the analysis, allowing for thorough and detailed mapping. The work involved securing online data from reliable sources to ensure the latest, highest quality, and most accurate imagery available for each year. This process ensured that the imagery for each year (2020-2023) is consistent in terms of quality, resolution, and inherited image characteristics such as sun illumination and sunlight angle.

The work employed remote sensing techniques and GIS platforms to delineate PV panels. The open source QGIS, was used in the mapping process. It has robust capabilities in handling high-resolution imagery and performing complex analyses. More specifically, advanced techniques were adopted to identify and analyze solar panel installations across Lebanon.

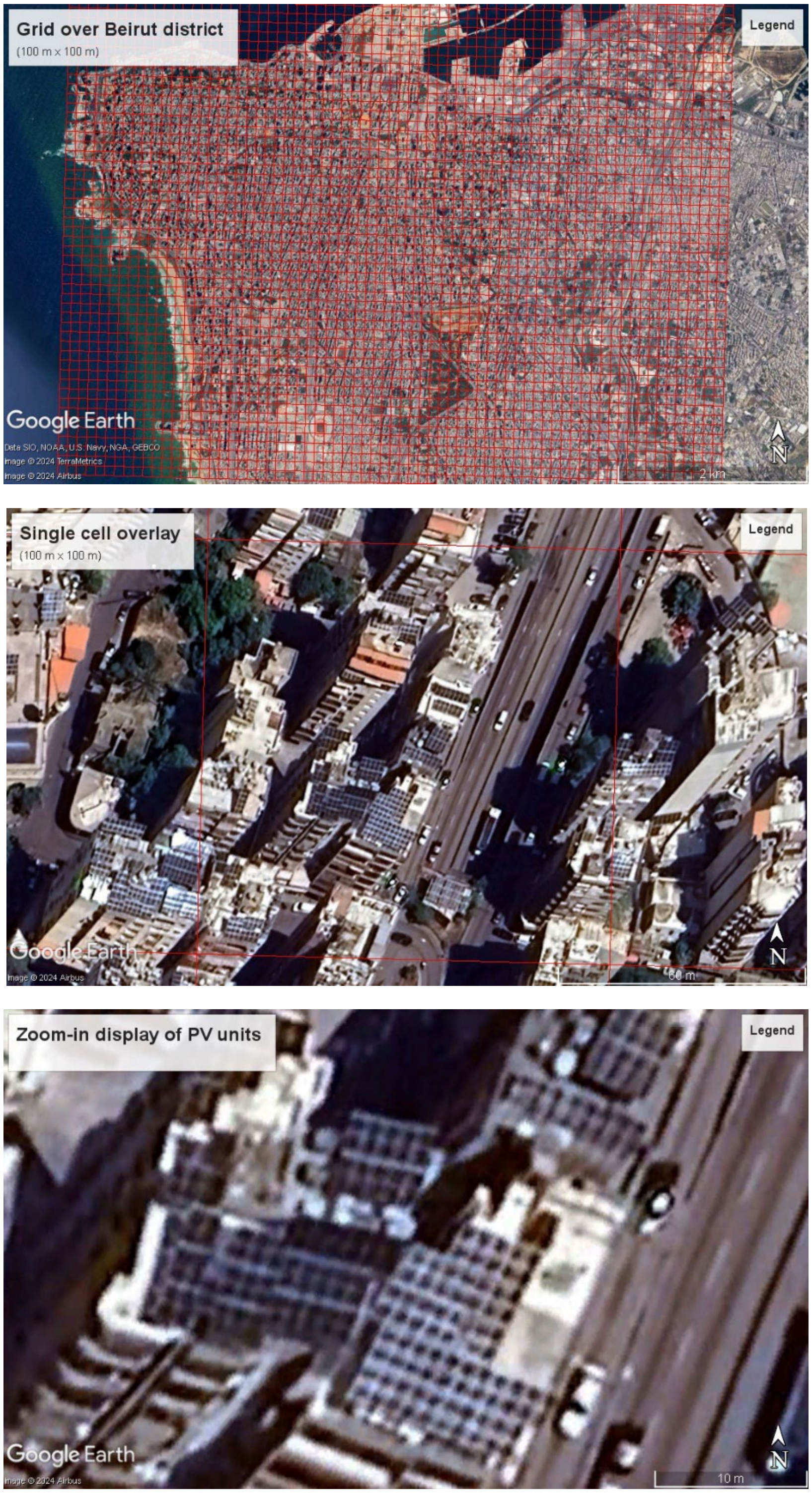

Figure 3: A gridded approach for identifying PV units

The geometric shapes and arrangements typical of solar PV panel installations were considered in the delineation process. The mapping techniques utilized to differentiate between PV panels and solar water heating panels were based on several key characteristics, such as brightness, shape, size, and texture:

- **Brightness and surface texture**: Brightness refers to a spectral feature that indicates the overall intensity of light reflected or emitted by an object across all spectral bands. Essentially, it measures how bright or dark a pixel or an object is by averaging the reflectance values across multiple bands of an image. Brightness is often used to distinguish between features in remote sensing images. PV panels typically exhibit a more reflective surface (specifically brightness) with a specific geometric pattern since they are composed of multiple photovoltaic cells arranged in a grid-like configuration. In contrast, solar water heating panels tend to have a darker, more homogeneous reflection due to their smooth, uniform surface, which lacks the cell structure seen in PV panels. This difference in reflectance and surface texture allowed the mapping system to distinguish between the two types of installations.

- **Size and arrangement**: Solar water heating panels are generally smaller in size, often appearing as individual, separate units on rooftops. PV panels, on the other hand, are usually installed in larger arrays to maximize energy production. The size and arrangement of these panels were a crucial factor in differentiation – PV systems often cover a larger surface area in a regular, grid-like pattern, while solar water heating systems are dispersed and irregular in arrangement.

By considering these factors such as brightness, texture, and size, the mapping techniques were able to differentiate between PV panels and solar water heating panels, ensuring better capabilities for mapping solar PV installations.

The use of image object-analysis on image subsets highlighted some main spectral differences between PV objects and solar heating objects. Image object analysis of high-resolution satellite images involves segmenting the image into meaningful regions, called **image objects**, based on both spectral and spatial characteristics (such as color, texture, and shape). Unlike pixel-based analysis, which classifies each pixel independently, object-based analysis groups neighboring pixels with similar properties into objects. These objects are then analyzed based on their features, allowing for more accurate classification of images and objects (Figure 4 and Figure 5).

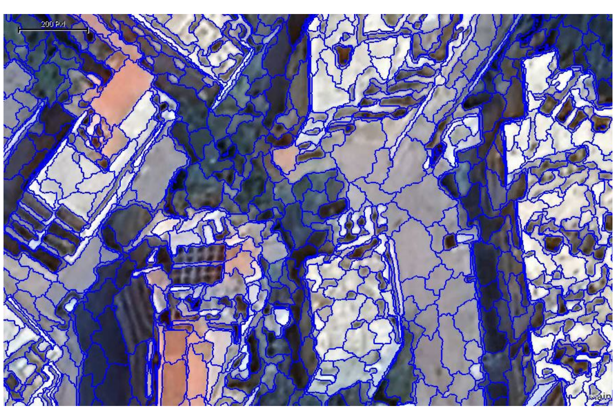

Figure 4: Image objects

Figure 5: Classified objects

The higher object brightness of classified PV panels suggests they are more reflective in the visible spectrum, which might be due to their material properties, coatings, or design, allowing them to reflect more light. In contrast, water heating panel objects are likely designed to absorb more sunlight (for heating purposes), which results in a darker appearance in the visible range (Figure 6).

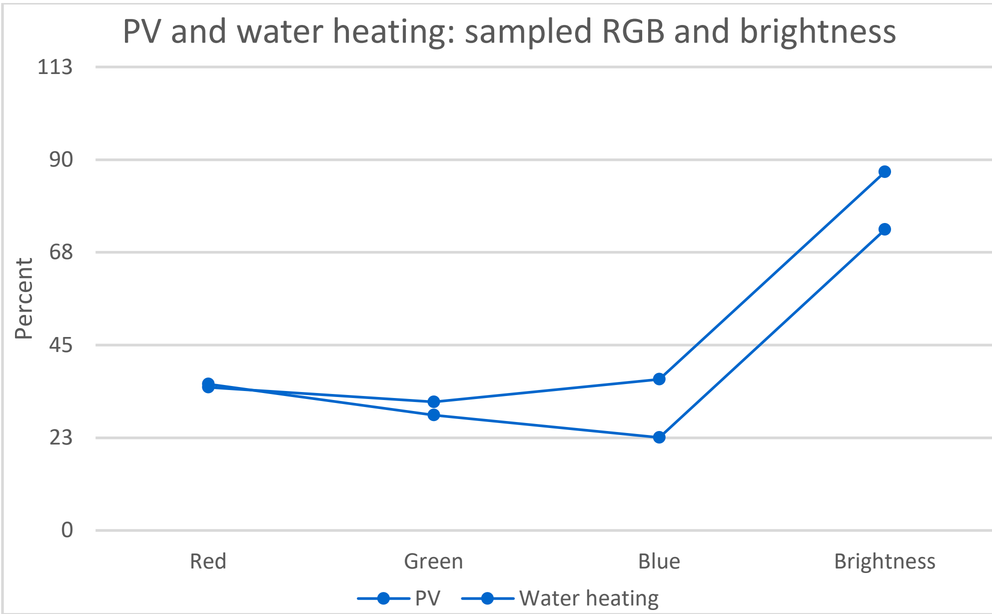

Figure 6: PV and water heating sampled object values in the Red, Green, and Blue visible bands and associated average brightness

Here, visual interpretation is one of the most traditional methods of image classification; it involves human interpretation of the satellite imagery based on the observer's knowledge and expertise. Analysts visually examined features such as brightness, shape, size, texture, pattern, and context within the image to distinguish between different objects. Visual interpretation is widely used to support automated classification results and to manually classify features that are difficult to distinguish through automated methods alone. However, the process is labor-intensive.

Visual interpretation was combined with manual classification, often supported by expert knowledge and ground truth data. This approach is commonly used to improve the precision of the classification. It is worth noting that manual classification is particularly valuable when dealing with high-resolution satellite images that contain intricate details, such as urban features across heterogeneous landscapes (e.g., the distribution of PV panels across different topographic regions in the country).

The limited combination of object-based image analysis and manual classification in certain districts, particularly in complex urban settings like the Beirut district, enabled the extraction of spectral and contextual information to enhance and facilitate the classification process.

Consequently, change detection techniques were applied to satellite images from different years to identify new installations of solar panels between 2020 and 2023. By comparing these images over time, it was possible to pinpoint new solar panel installations.

Each solar panel installation was meticulously mapped, highlighting both concentrations and sparse areas of solar energy deployment. The year of installation was also recorded. The surface area covered by the solar panels was calculated.

In this report, map displays of the different datasets involved the use of Natural Breaks (Jenks) classification, which is a data classification method commonly used by dividing data into meaningful categories based on inherent patterns. Specifically, the algorithm is designed to identify "breaks" or gaps in a dataset. It groups data into classes where each class has similar values, and the differences between classes are maximized. This method minimizes the variance within each class while maximizing the variance between classes, making it ideal for displaying patterns in geographical or spatial data.

Overall, the variations in density among confirmed panels, PV panels area, and MWp values as seen in different districts can arise from multiple factors influencing the distribution and density of solar PV installations. The year of installation can have a significant impact on the distribution. Older installations might have been smaller and more distributed, while newer ones could be larger. Districts may vary in the typical sizes of PV systems installed. For example, some areas, especially residential or densely populated urban districts, may have many smaller installations (leading to a higher number of panels but lower total area). Conversely, more industrial or agricultural areas might have larger installations with fewer but bigger panels, resulting in a higher total PV area and MWp but fewer individual confirmed panels.

The available roof space, land, and building types can influence PV installations. Residential areas with limited rooftop space may lead to smaller systems, while districts with more open space or larger rooftops might host bigger installations. Economic factors, such as resident wealth or the prevalence of industries that benefit from energy independence, can also impact the adoption rate and system sizes.

To calculate the real flat area from the mapped area of a surface that is inclined at an angle, the angle of the slope was accounted for. The relationship between the mapped area (A_mapped) on an inclined surface and the real flat area (A_flat) is given by the cosine of the angle of inclination (θ):

A_flat = A_mapped/cos(θ) - In this case, the maximum θ was assumed at 30 degrees; therefore cos(θ) = 0.866

The choice to calculate the real flat area from the mapped area of an inclined surface using the cosine of the angle of inclination is grounded in basic geometric principles and is commonly used in remote sensing and Geographic Information System (GIS) applications. A 30 degrees cosine is a maximum value with reference to a focused survey conducted within the context of this work in 2024 towards a total of 22 active solar energy companies in Lebanon (Table 1). An average inclination angle of 21.9 degrees was estimated for installed PV panels in Lebanon.

Table 1: Surveyed values of inclination angle of PV panels

	Average	Minimum	Maximum	Most common	Nb. of respondents*
Inclination Angle (◦)	21.9	12	30	20	22

**Data provided by Nader H. S. (2024)*

Each solar panel was assigned a unique ID, and its geographic coordinates, location (town or village), mapping area, rectified or corrected surface area in square meters, were recorded.

The mapping tasks were conducted at the district level for each year from 2020 to 2023. However, for certain districts, data on PV units for specific years was missing (gap estimated at 1.13% of the total mapped area). This was primarily due to the unavailability of corresponding satellite tiles or coverage and the presence of cloud cover during the imaging periods, among other factors. These limitations hindered the ability to capture and map the PV units accurately for those years.

To address the missing data, interpolation and extrapolation techniques were employed. These methods filled in the gaps by using the average percentage of installed and mapped PV units for each year, based on the available data where PV units were successfully mapped for consecutive years. This approach ensured a more complete and accurate representation of the installed PV units across all districts for the years 2020 to 2023. In this context, interpolation and extrapolation are commonly used in data analysis to estimate missing values based on known data points. In particular, a linear interpolation was used to estimate missing data points within the range of known data points. In this case, if the data for installed PV units is available for some years but missing for others within the same time period, interpolation can fill in those gaps. Linear extrapolation was used to estimate data points beyond the range of known data. In this case, if the data is missing for years beyond the available data, extrapolation techniques can estimate these values based on the trend observed in the known data.

Calculation of annual energy production addition

The adopted equation for the calculation of the annual energy production addition in Lebanon is considered as follows:

$E = CF \times 8{,}760 \times kWp$ Equation 1

Where,

E: Annual energy production addition (kWh)
CF: Capacity Factor – 0.1633 for Lebanon
kWp: Annual kilowatt-peak produced by the total area of installed PV panels

The capacity factor (CF) is an important parameter used in the assessment of the operation of PV panels. By definition, the CF is the ratio of the actual electrical energy production over a given period of time to the maximum possible electrical energy output during the same time period (REPN, 2017). In this work, the CF is the ratio of annual energy in kWh to system capacity in kWp multiplied by 365 days and 24 hours (i.e., multiplied by 8,760).

The literature review did not reveal any official CF specific to Lebanon. However, factors presented in some publications were collected, and those used specifically by LCEC were analyzed to determine a CF value for use in this work. As a result, the average value of 0.1633 for the year 2020 and the years ≤2020 was adopted.

Table 2: Summary table of CF factors

Reference	Year	CF	Link
Re-Energize Lebanon	2022	0.21	https://www.aub.edu.lb/ifi/Documents/publications/research_reports/2022-2023/Re-energize%20Lebanon%20Feb%202023.pdf
DREI Report	2016	0.198	https://www.undp.org/sites/g/files/zskgke326/files/2022-09/DREI%20Lebanon%20Full%20Report%20%28English%29%20%28Sep%202017%29%20%28FINAL%29.pdf
Distributed Power – World Bank	2020	0.16	https://documents1.worldbank.org/curated/en/353531589865018948/pdf/Distributed-Power-Generation-for-Lebanon-Market-Assessment-and-Policy-Pathways.pdf
IFI – Water Energy Nexus	2019	0.16	https://www.aub.edu.lb/ifi/Documents/publications/research_reports/2020-2021/202106_water_energy_nexus_volume_4_pdf.pdf
LCEC Report 2020 (Computed)	2020	0.1627	
LCEC Report 2020 (Computed)	≤2020	0.1639	
LCEC Report 2020 (Computed)	2019	0.1424	https://www.lcec.org.lb/sites/default/files/2022-08/2020%20Solar%20PV%20Status%20Report%20-%20Final.pdf
LCEC Report 2020 (Computed)	≤2019	0.1642	https://www.lcec.org.lb/sites/default/files/2022-08/2020%20Solar%20PV%20Status%20Report%20-%20Final.pdf
LCEC Report 2020 (Computed)	≤2018	0.1726%	

The average kWp per square meter (m^2) of PV panels can vary depending on the type and efficiency of the panels. As of 2024, typical solar panels produce between 0.15 kWp to 0.22 kWp per m^2. This range is based on the efficiency of modern solar panels, which generally ranges from 15% to 22% (Fraunhofer, 2024).

Some values regarding the average kilowatt-peak (kWp) per square meter (m^2) of PV panels from 2020 through 2023 are based on available studies and reports and are as follows (Green et al., 2020; IEA, 2021; Fraunhofer, 2022; NREL, 2023):

- **Year 2020**: the average kWp per m^2 for standard crystalline silicon solar panels was around 0.16 to 0.18 kWp/m^2. This is based on typical efficiencies of 16 -18%.
- **Year 2021**: The efficiency continued to improve slightly, with values ranging from 0.17 to 0.19 kWp/m^2.
- **Year 2022**: Due to further advancements in technology, including bifacial and high-efficiency panels, the average kWp per m^2 increased to around 0.18 to 0.20 kWp/m^2.
- **Year 2023**: With the introduction of next-generation high-efficiency panels, particularly those using Passivated Emitter and Rear Cell (PERC) technology, the average kWp per m^2 has reached 0.19 to 0.22 kWp/m^2.

In this analysis, the lower kWp values for each year were used in the calculations, specifically 16% for 2020, 17% for 2021, 18% for 2022, and 19% for 2023. In addition, the calculated average total area of installed PV panels for each year was considered.

V. MAPPING RESULTS

Area and distribution of PV panels

A spatial representation of identified and mapped PV units in Lebanon (i.e., total mapped areas between 2020 and 2023) is presented in Figure 7.

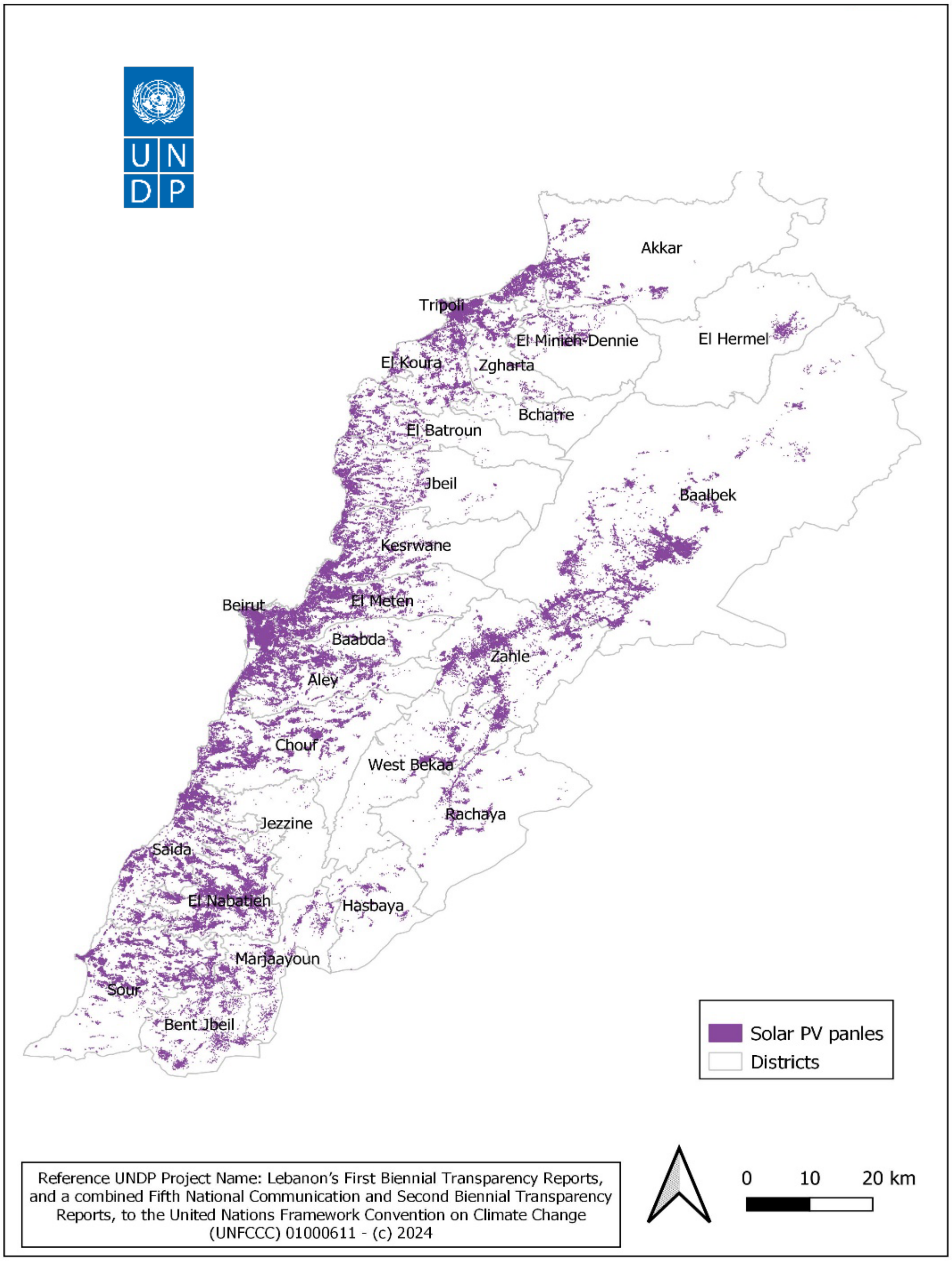

Figure 7: Distribution of individually mapped PV until 2023

The cumulative number of solar PV units identified and mapped amounted to **241,298 units** distributed with great variabilities across the different districts (Figure 8).

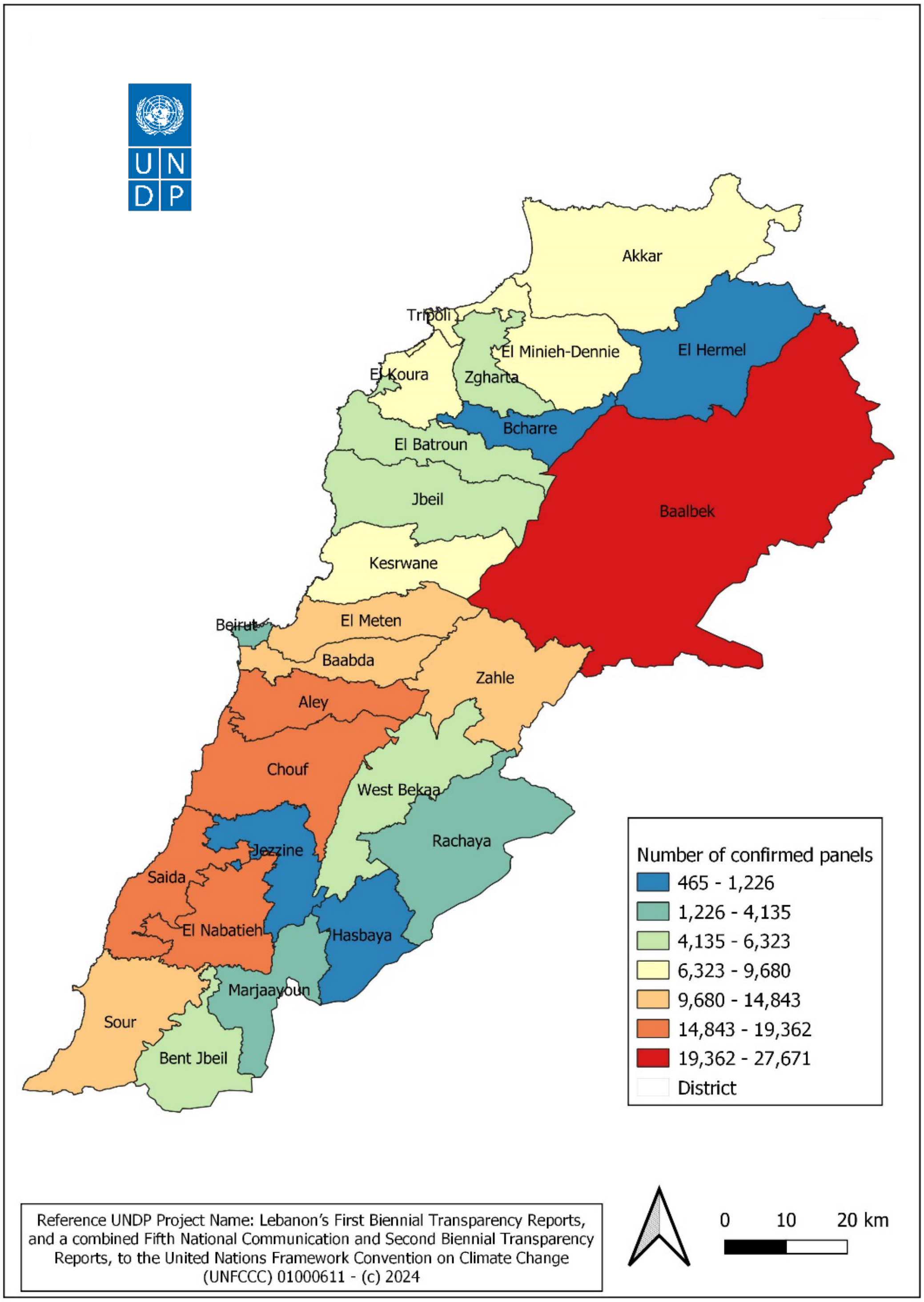

Figure 8: Distribution of cumulative number of identified solar PV panels per district by 2023

The cumulative maximum (with an inclination angle of 30 degrees), average (with an inclination angle of 21.9 degrees), and minimum (with an inclination angle of 20 degrees) areas mapped for PV installations by the year 2023 are significant, amounting to 7,349,416.77 m^2, **6,858,399.70 m^2** (used in this study, as it is close to the commonly applied inclination angle of 20 degrees), and 6,507,765.77 m^2, respectively.

The tables in **Annex 1. Detailed spatial distribution of assessed solar PV unit installations across various districts in Lebanon** provide a detailed spatial distribution of assessed solar PV unit installations across various districts in Lebanon, spanning the years from 2020 to 2023. The data includes the cumulative identified number of mapped PV units, the mapping area for each year (i.e., after correction/rectification), and the total derived area of PV units for each district (i.e., after the application of interpolation and extrapolation for specific cases).

The year-to-year increase in cumulative areas of installed solar PV panels across the different districts suggests robust growth in solar energy infrastructure (Figure 9). Notable districts with extensive PV unit installations include Baalbek, El Metn, Baabda, Saida, Zahleh, and Chouf reflecting high activity in these areas (Figure 10).

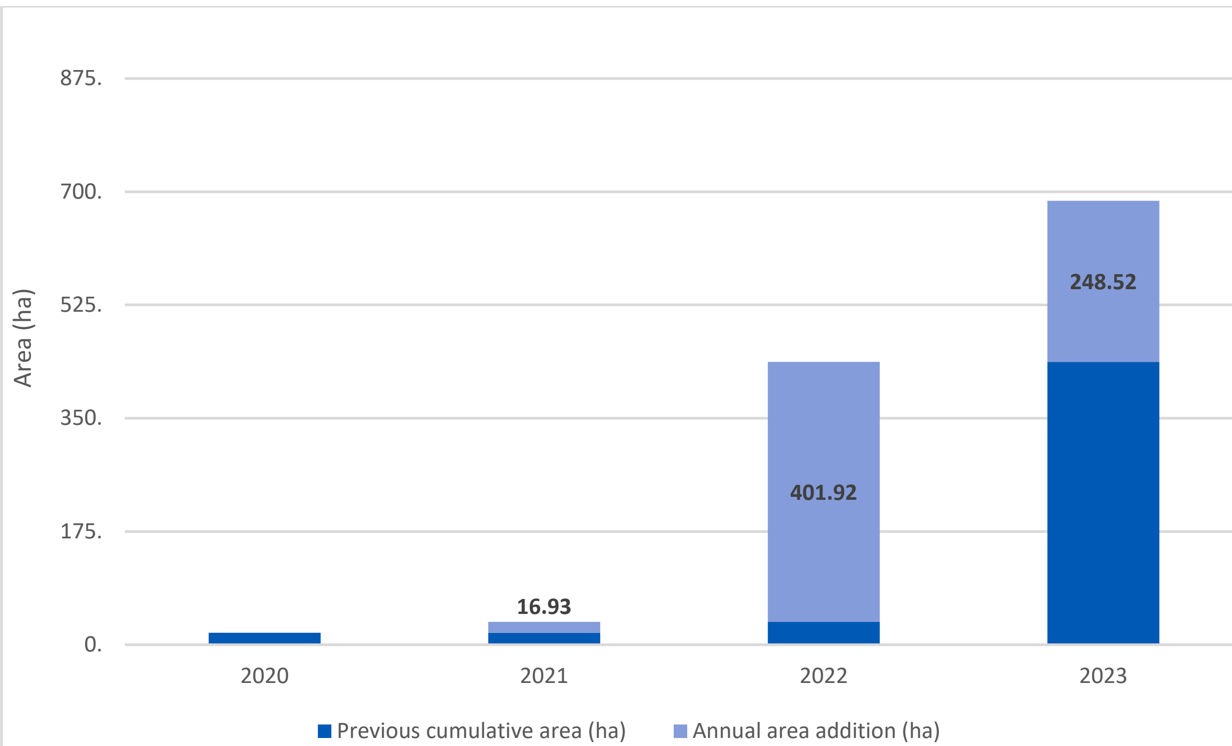

Figure 9: PV annual area additions and cumulative surface from 2020 throughout 2023 with high confidence

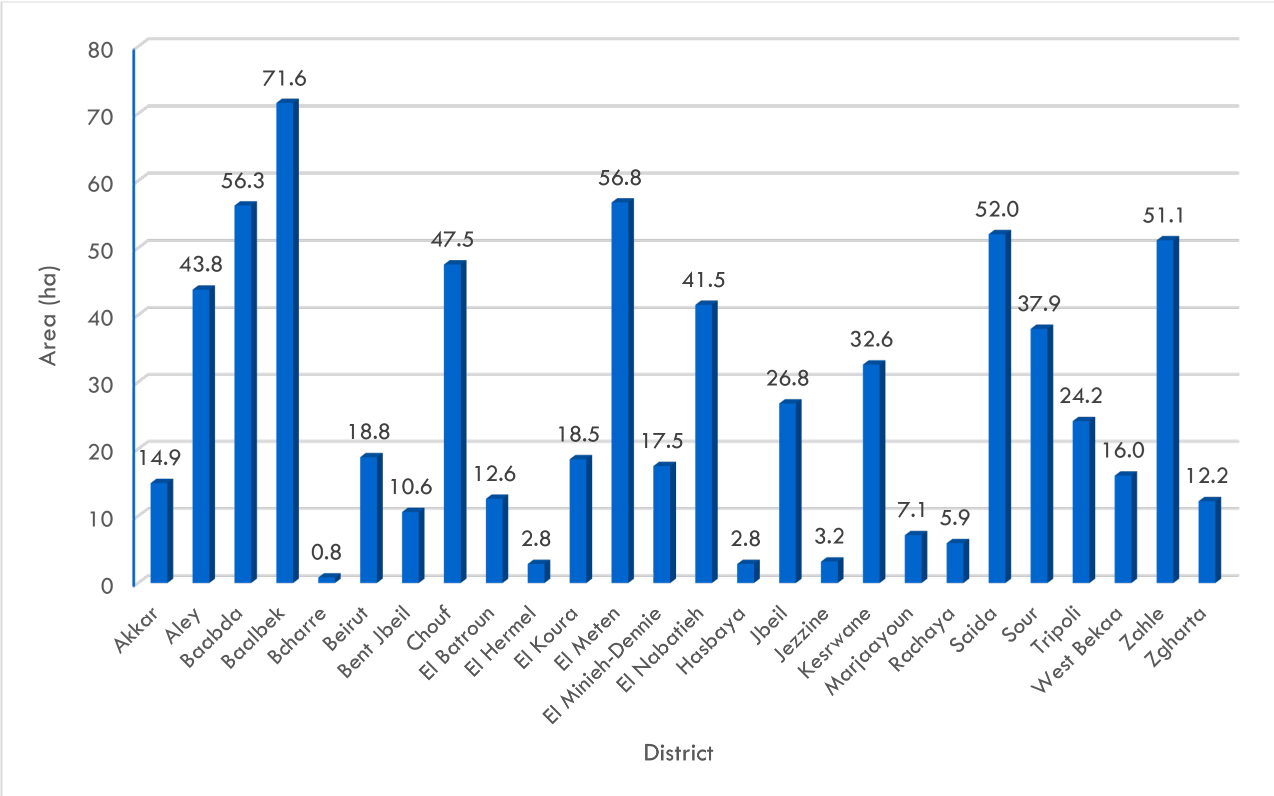

Figure 10: PV cumulative area (ha) in 2023 per district with high confidence

While some districts show significant increase in the area of PV panels installed, some other districts recorded minimal changes across the years. These observations provide a foundation for policymakers and planners to identify regions with high solar energy adoption and those that need more focus (Figure 11 to Figure 14).

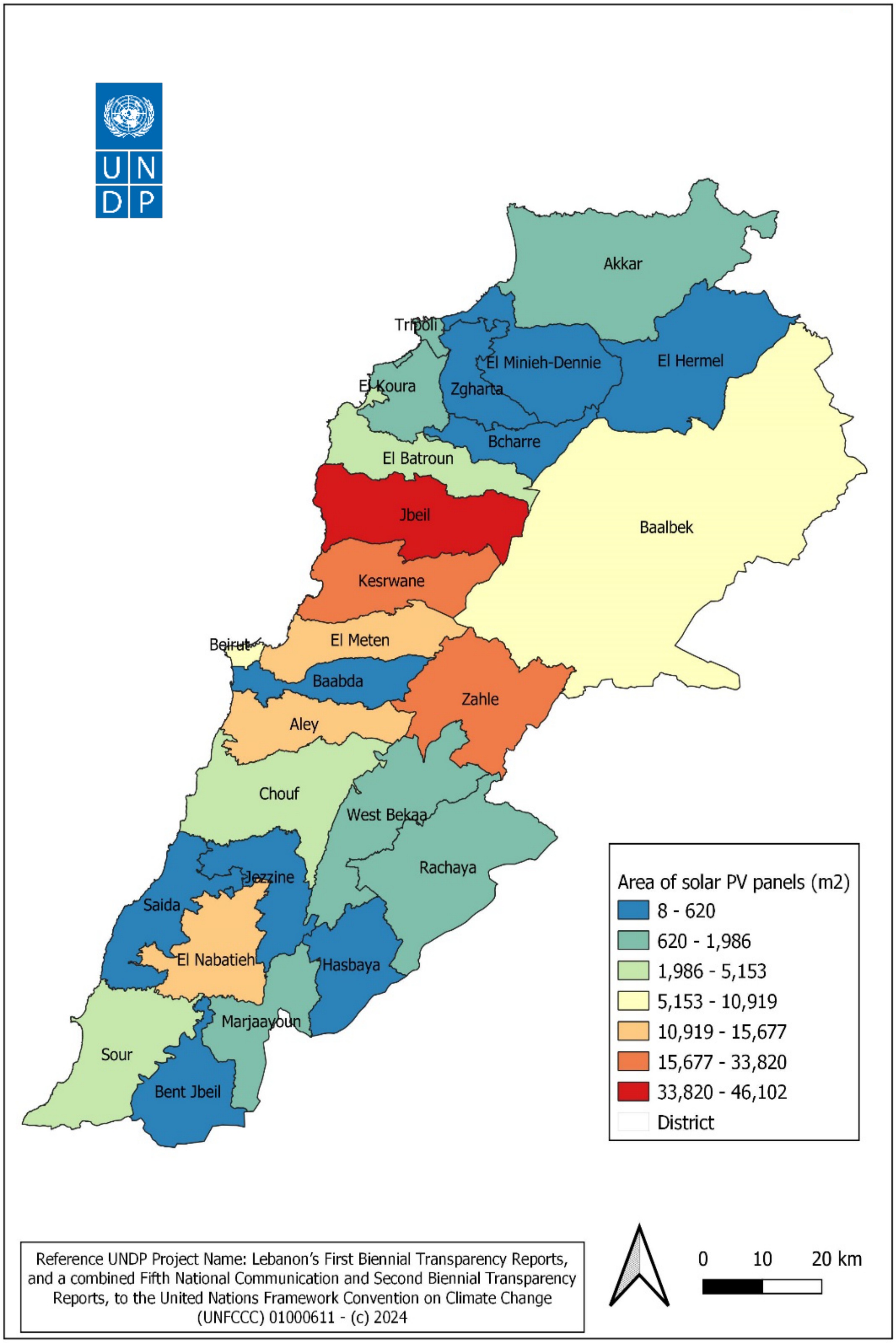

Figure 11: Area of solar PV panels in 2020

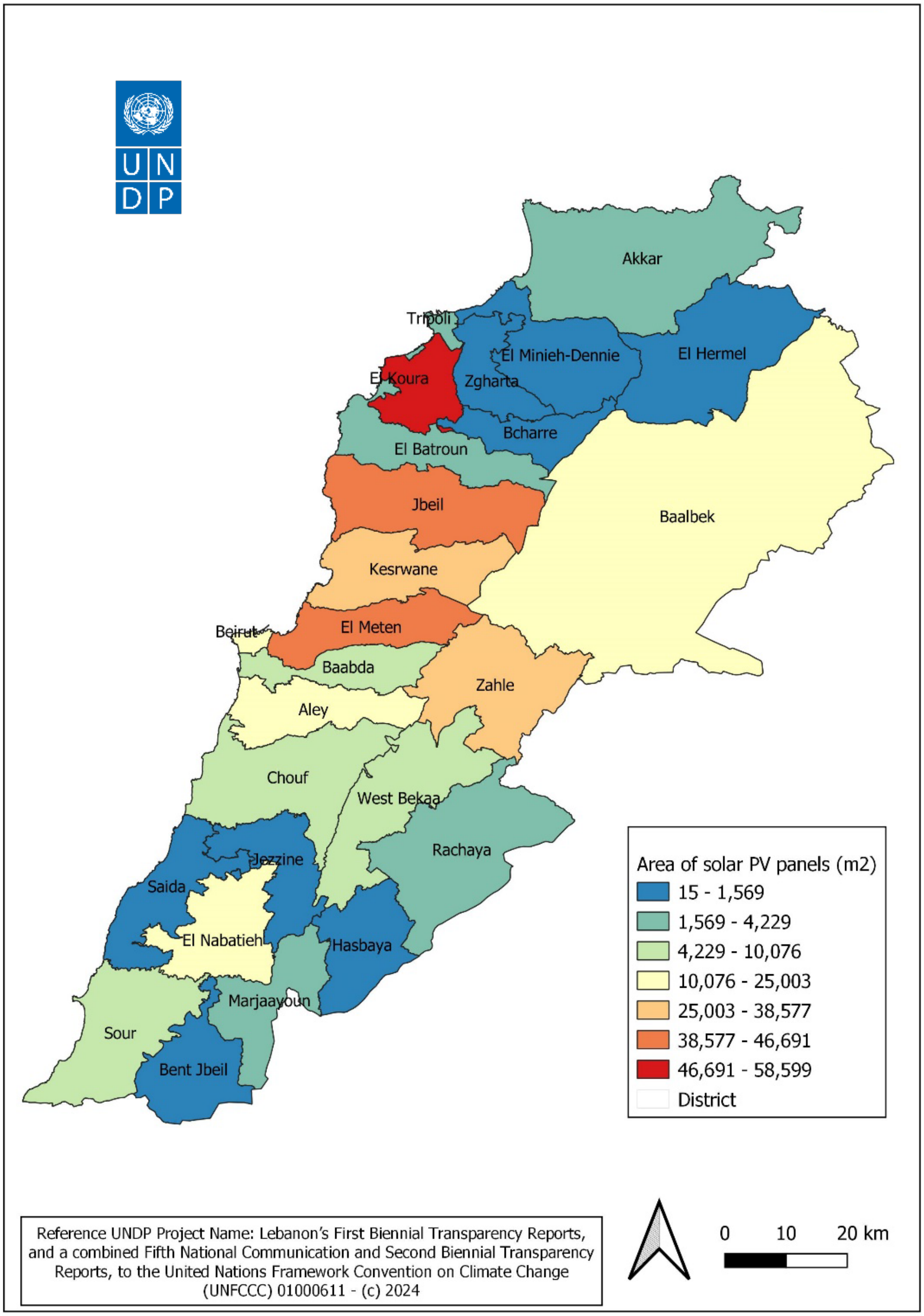

Figure 12: Cumulative area of solar PV panels in 2021

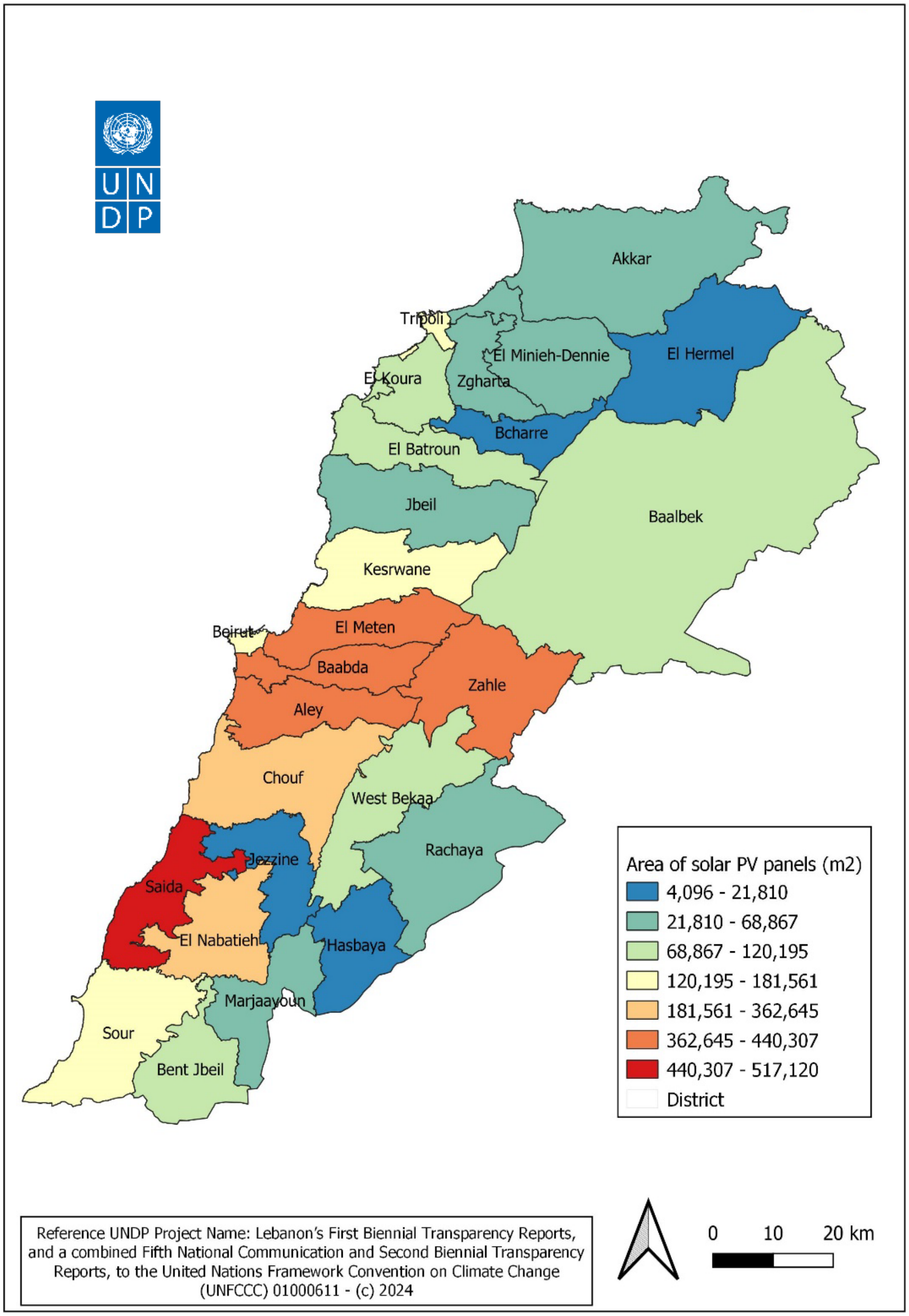

Figure 13: Cumulative area of solar PV panels in 2022

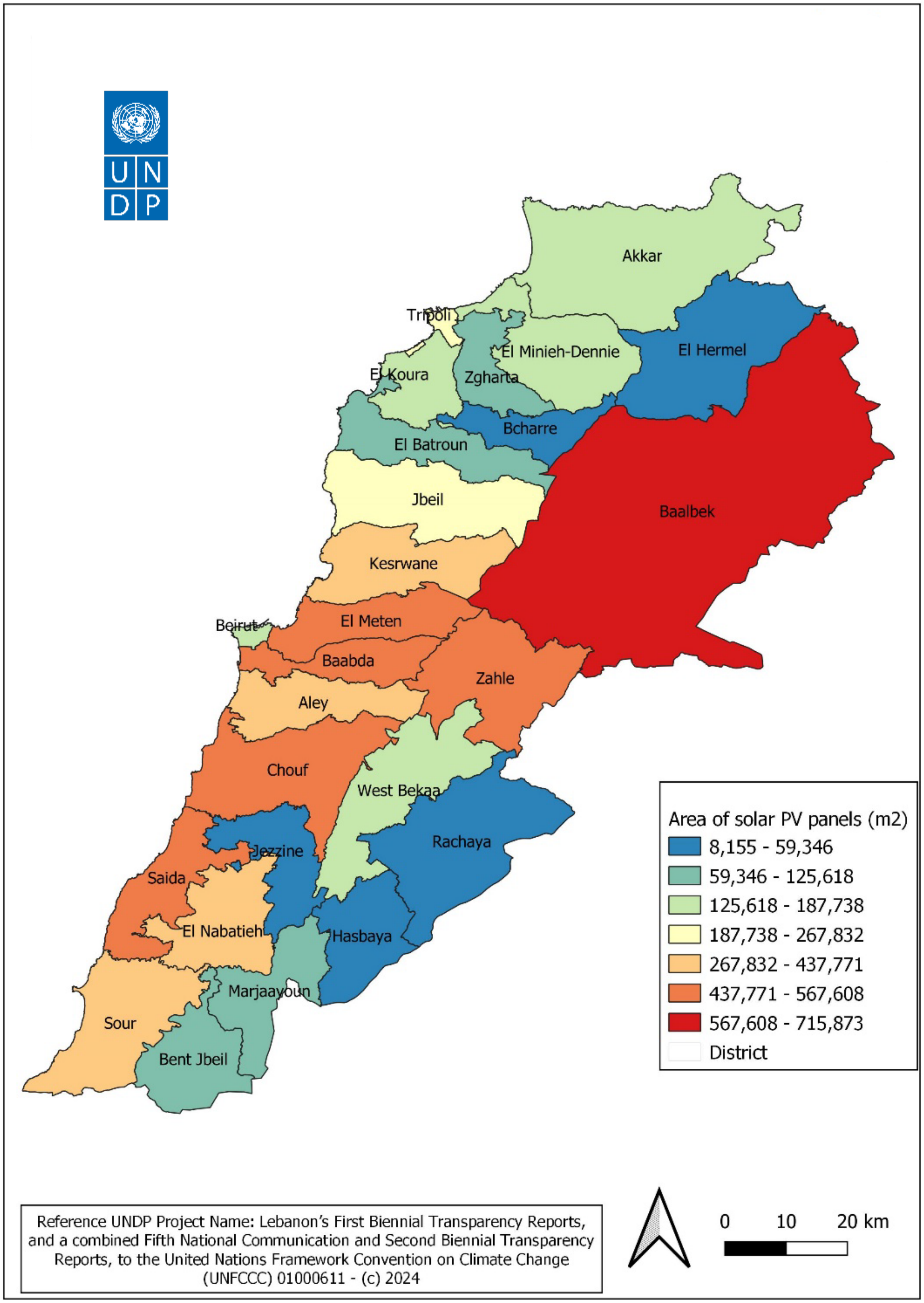

Figure 14: Cumulative area of solar PV panels in 2023

A further investigation into the results looked at changes in the average area of installed individual PV units from 2020 to 2023 (Figure 15). In 2020, the average area of individual installed PV units was significantly large at 370.05 m^2. By 2021, the average area dramatically decreased to 53.19 m^2, representing a sharp drop of over 85%. In 2022, the average area further reduced to 27.05 m^2. This shows that, while the decrease was not as drastic as between 2020 and 2021, there was still a significant reduction. The average area of individual PV units in 2023 rose slightly to 31.40 m^2. This increase indicates a minor rebound in the size of PV installations compared to the previous year, but it remains much lower than 2020.

The large average PV unit size in 2020 suggests that many of the installations were likely larger commercial or industrial projects. During this period, economic conditions or incentives might have favored the deployment of larger systems over smaller ones for households. However, the sharp drop in 2021 could be attributed to several factors such as a shift toward smaller-scale, more distributed solar PV installations (e.g., residential systems).

The continued decline in 2022 further supports the trend of smaller individual installations, possibly as a response to economic challenges or as more households and businesses turned to solar energy on a smaller scale amid rising electricity costs. Yet, the slight increase in 2023 could indicate renewed interest in larger PV systems, potentially driven by improved economic conditions and stabilization of the market after the initial rush for smaller-scale systems in previous years.

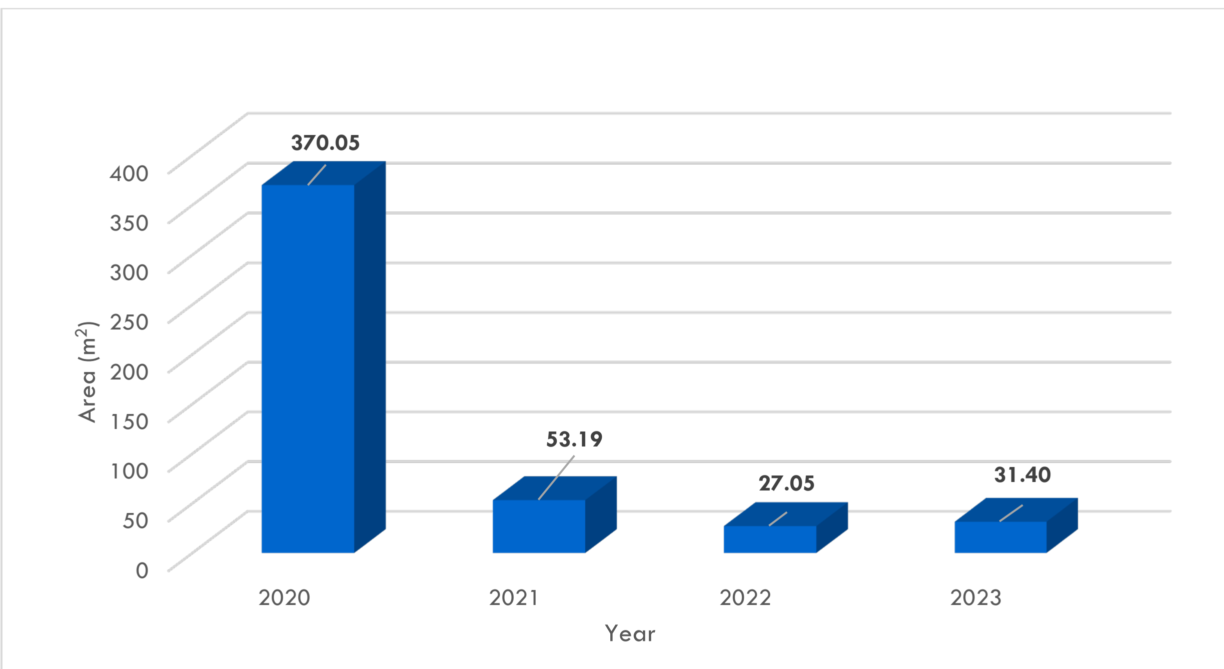

Figure 15: Change in average area of installed individual PV units at the national level

Distribution of annual energy production additions

As of 2020, the year-to-year percentage increase of the cumulative installed capacity was as follows:

- 97.4% resulting in a capacity of 58.33 MWp in 2021
- 1,240.18% resulting in capacity if 781.78 MWp in 2022
- 60.4% resulting in capacity of 1,253.98 MWp in 2023

The installed capacity of solar PV increased from 29.55 MWp in 2020 to 1,253.98 MWp in 2023 (Figure 16).

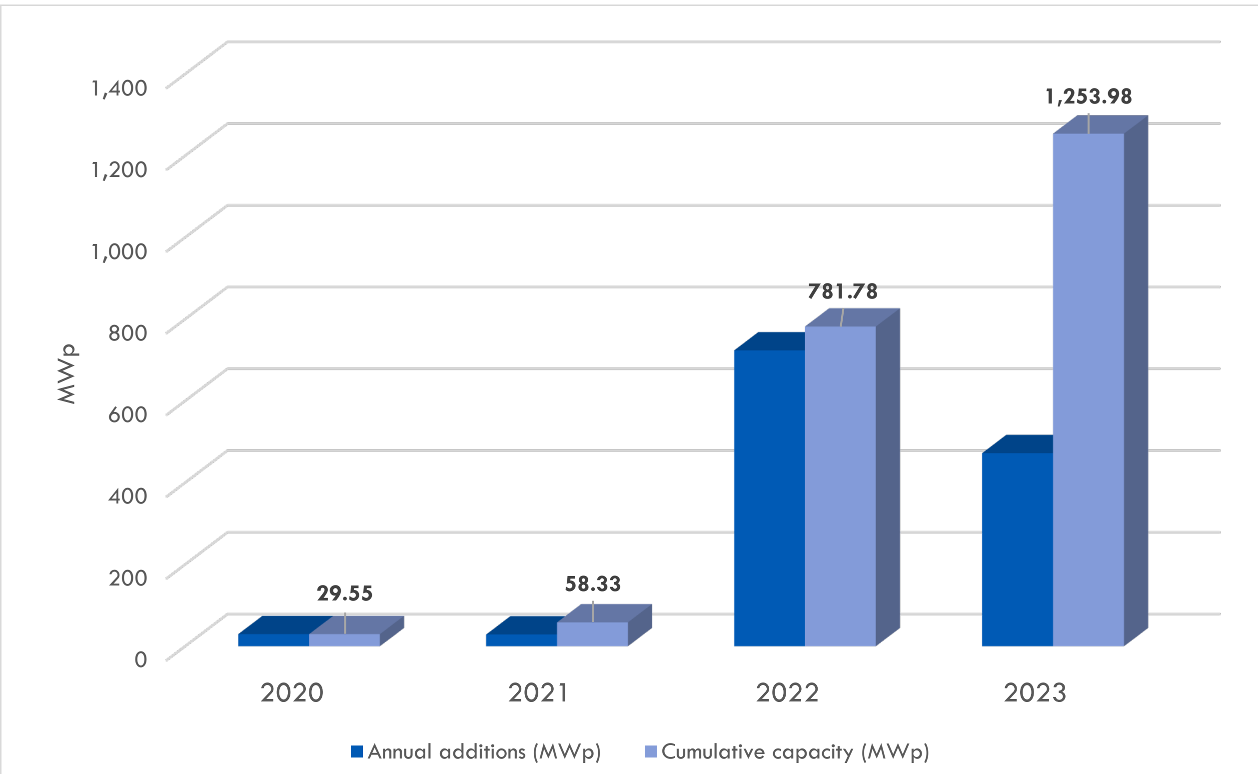

Figure 16: Solar PV cumulative capacity and annual additions

More specifically, the various maps of cumulative capacity of solar PV panels display the distribution of solar PV capacity across different districts in Lebanon (Figure 17– Figure 20). By 2023, the Baalbek district stood out as the district with the highest cumulative solar PV capacity. This indicates significant solar energy development in this region. Districts such as Zahle, El Hermel, Saida, Chouf, and Jezzine have moderately high cumulative capacities. Overall, the maps highlight significant disparities in solar PV capacity across different regions in Lebanon. Some districts have aggressively adopted solar PV, while others lag behind. This trend is also related to the density of households in each district.

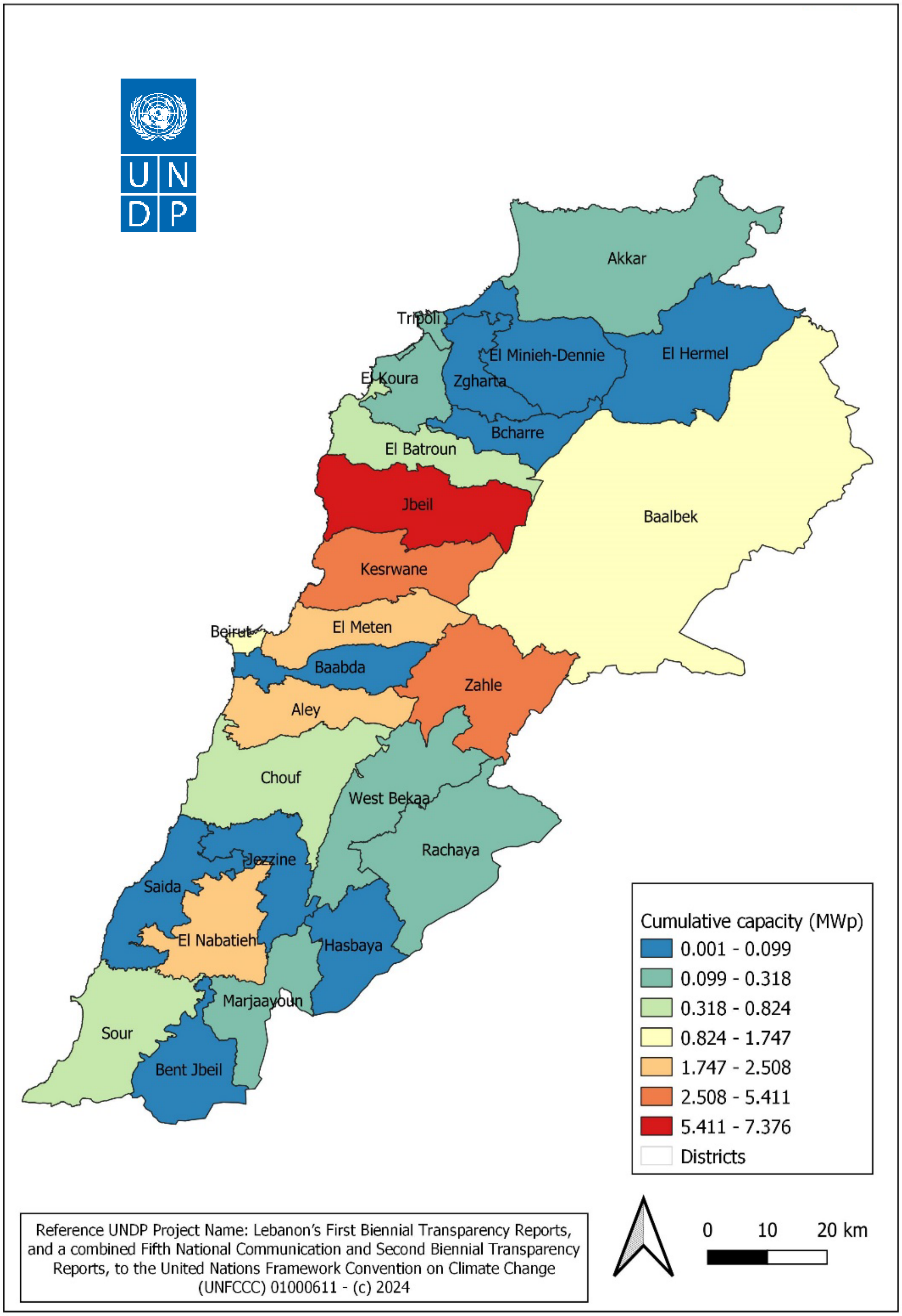

Figure 17: Cumulative capacity of installed solar PV panels in 2020

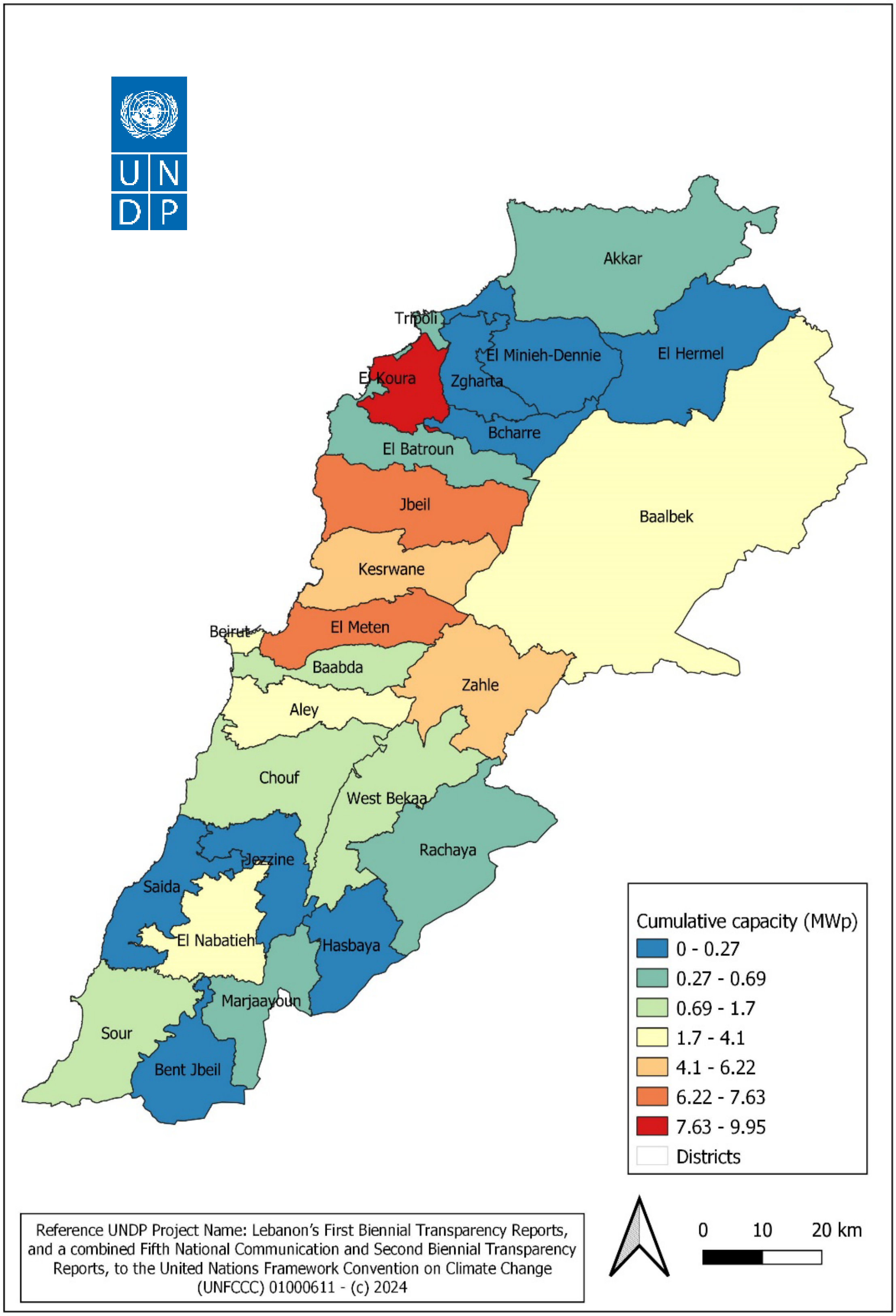

Figure 18: Cumulative capacity of installed solar PV panels in 2021

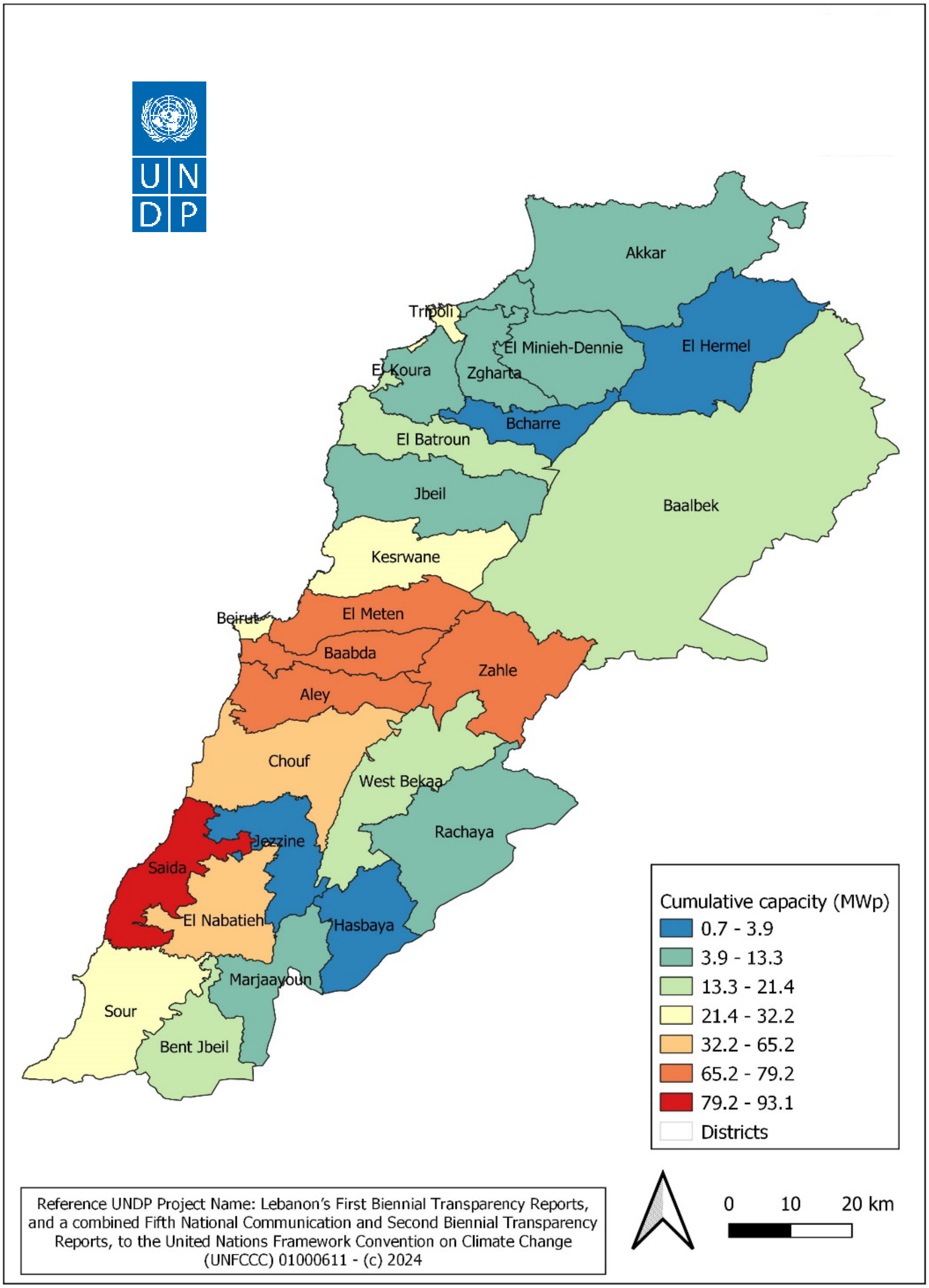

Figure 19: Cumulative capacity of installed solar PV panels in 2022

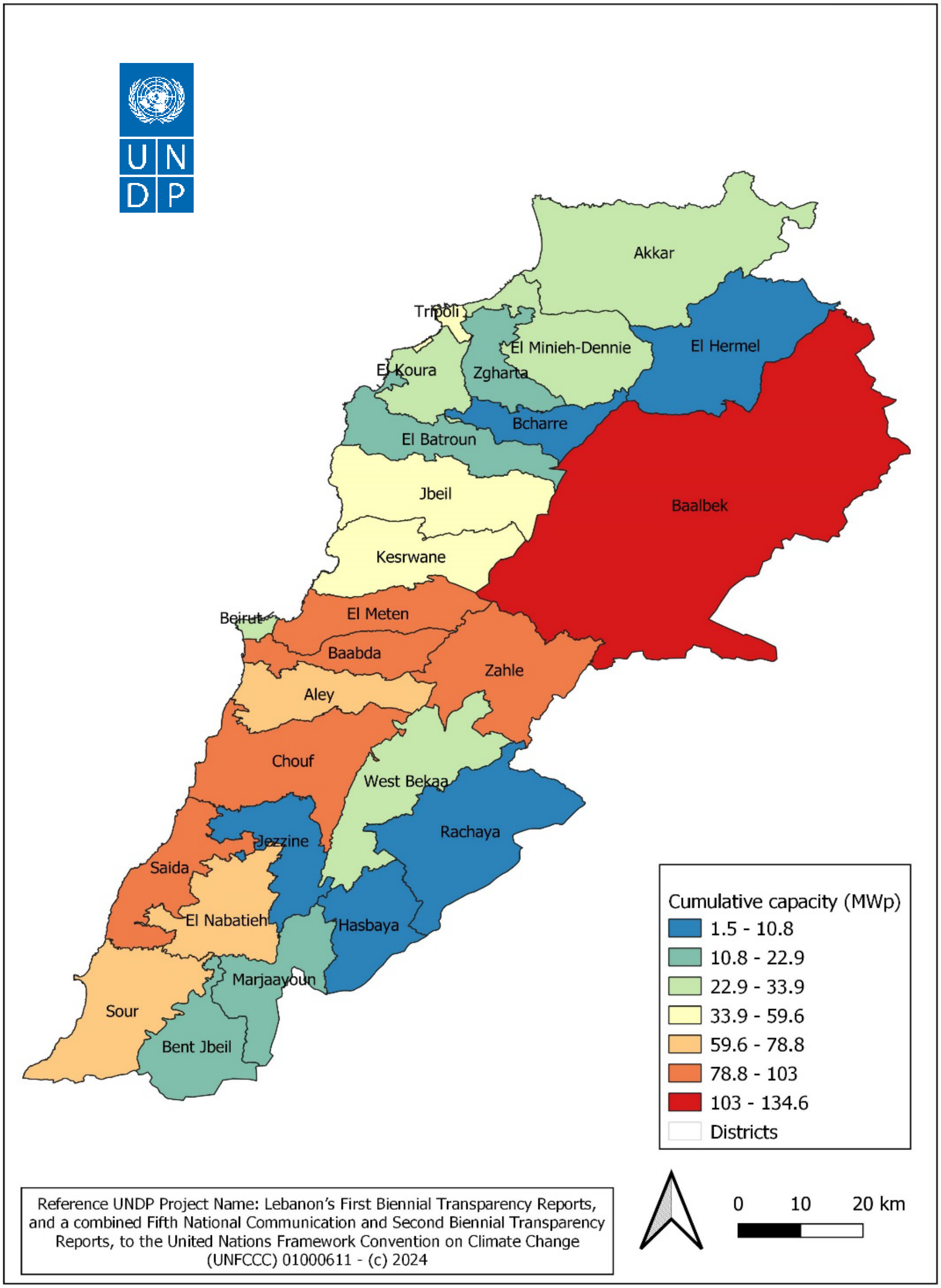

Figure 20: Cumulative capacity of installed solar PV panels in 2023

The additional installed capacities of solar PV led to an increase of energy generation from 0.08 TWh in 2021 to 1.11 TWh in 2022 and 1.79 TWh in 2023 (Figure 21).

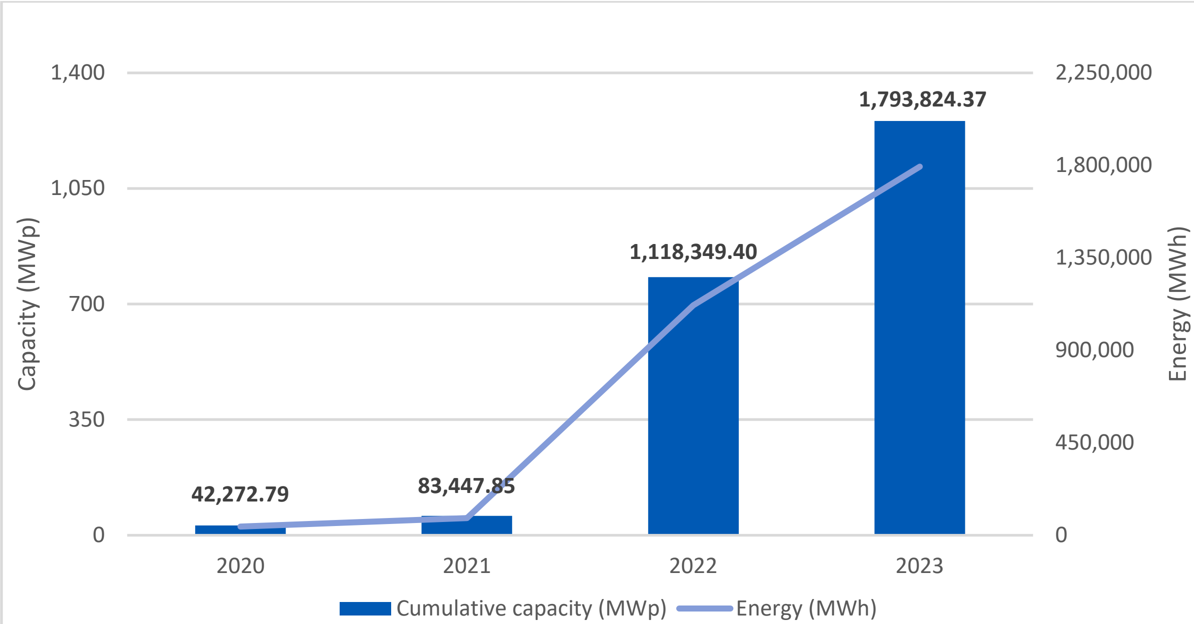

Figure 21: Solar PV capacity and generation

The cumulative energy production of solar PV panels in 2023 shows the distribution of solar PV energy production across different districts in Lebanon, measured in megawatt-hours (MWh). There are significant regional disparities in energy production, just like there are disparities in capacity. Some districts are leading in solar energy production, while others have much lower output, potentially due to less installed capacity or less favorable solar conditions (Figure 22).

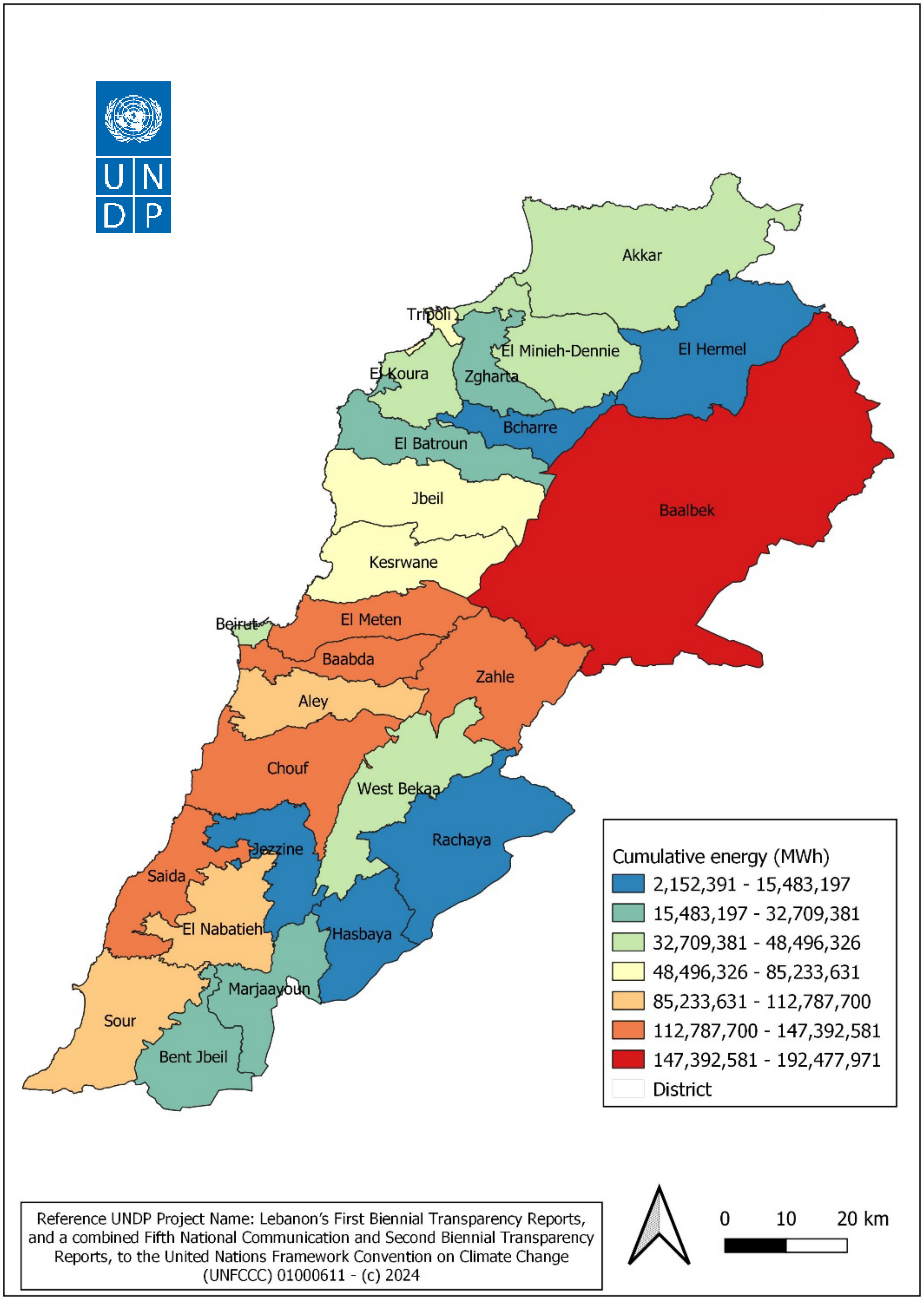

Figure 22: Cumulative energy production from installed solar PV panels in 2023

VI. WAR IMPACT ON INSTALLED PV UNITS

Source: Aziz Taher/Reuters

People walk on the rubble of damaged buildings and collapsed PV solar panels in Tyre, southern Lebanon.

Lebanon has been facing a devastating conflict since October 2023, with heavy military operations concentrated in southern Beirut suburbs and the southern border regions. The war has caused widespread destruction to infrastructure, among which the infrastructure of PV solar panel installations.

To assess the potential destruction of PV panels across Lebanon, multi-temporal Sentinel-1 SAR data were employed. By analyzing changes in backscatter values before and after the conflict, a scoring system was developed to classify damage probability levels. This assessment is crucial for:

- Quantifying losses in the renewable energy sector.
- Identifying priority areas for post-war energy restoration.
- Informing national and international recovery efforts.

Given Lebanon's energy vulnerability and reliance on decentralized solar power, understanding the war's impact on PV infrastructure is essential for planning effective reconstruction strategies and ensuring the long-term sustainability of the country's energy transition.

Methodology of assessment

This brief methodology outlines the steps taken to assess the potential damage of PV panels in Lebanon (i.e., those identified and mapped between 2020 and 2023) due to the 2024 war. The analysis leverages Sentinel-1 SAR data, focusing on changes in backscatter values (VV, VH) and their differences over time to infer damage levels. A scoring system was developed to classify PV panel damage probability based on SAR data variations.

Time series Sentinel-1 SAR imagery were acquired for the pre- war period (from January 1, 2023 until October 7, 2023) and post-war period (from December 1, 2024 until January 31, 2025). Both polarization channels, namely VV (Vertical transmit, Vertical receive) and VH (Vertical transmit, Horizontal receive) were averaged and employed. The VV channel is more sensitive to built-up structures, while the VH channel is effective in detecting roughness changes. Data was acquired from the Copernicus Open Access Hub and processed using a remote sensing and GIS platform.

To assess damage, the change in backscatter was calculated and investigated between the pre-war and post-war images. A median composite of all available Sentinel-1 images was computed for both the pre-war and post-war periods to reduce noise and improve the reliability of the analysis. The Normalized Difference Radar Index (NDRI) was computed for each period to assess changes in built-up areas. Sudden changes in NDRI between the two periods suggest destruction, rubble formation, or loss of structures. More specifically, areas with significant negative changes indicate a likely loss of reflectivity due to structural damage or debris coverage. Where applicable, this was complemented with interpretation of very high spatial resolution imagery and other data sources (e.g., cadastral units affected by war).

A categorical scoring approach was applied to classify potential damage levels based on backscatter changes. This methodology provided a systematic approach to estimating the destruction of PV panels due to war using Sentinel-1 SAR data. With the absence of field data, the scoring system enabled categorization of damaged areas.

Source: OnGEO-Intelligence

Figure 23: Google satellite image showing PV panels before the bombing in Haret Hreik, Baabda District

Source: OnGEO-Intelligence

Figure 24: Google satellite image showing PV panels after the bombing in Haret Hreik, Baabda District

Results and discussion

In this work a total of 2,751 PV solar independent units out of the 241,298 previously identified units were mapped as damaged with high confidence, totaling a rectified surface of 93,016 m^2, i.e., approximately 1.4% of the total cumulative PV area in 2023 (Figure 25). An additional 437 units were mapped as damaged with a lower confidence totaling a rectified surface of 11,045 m^2.

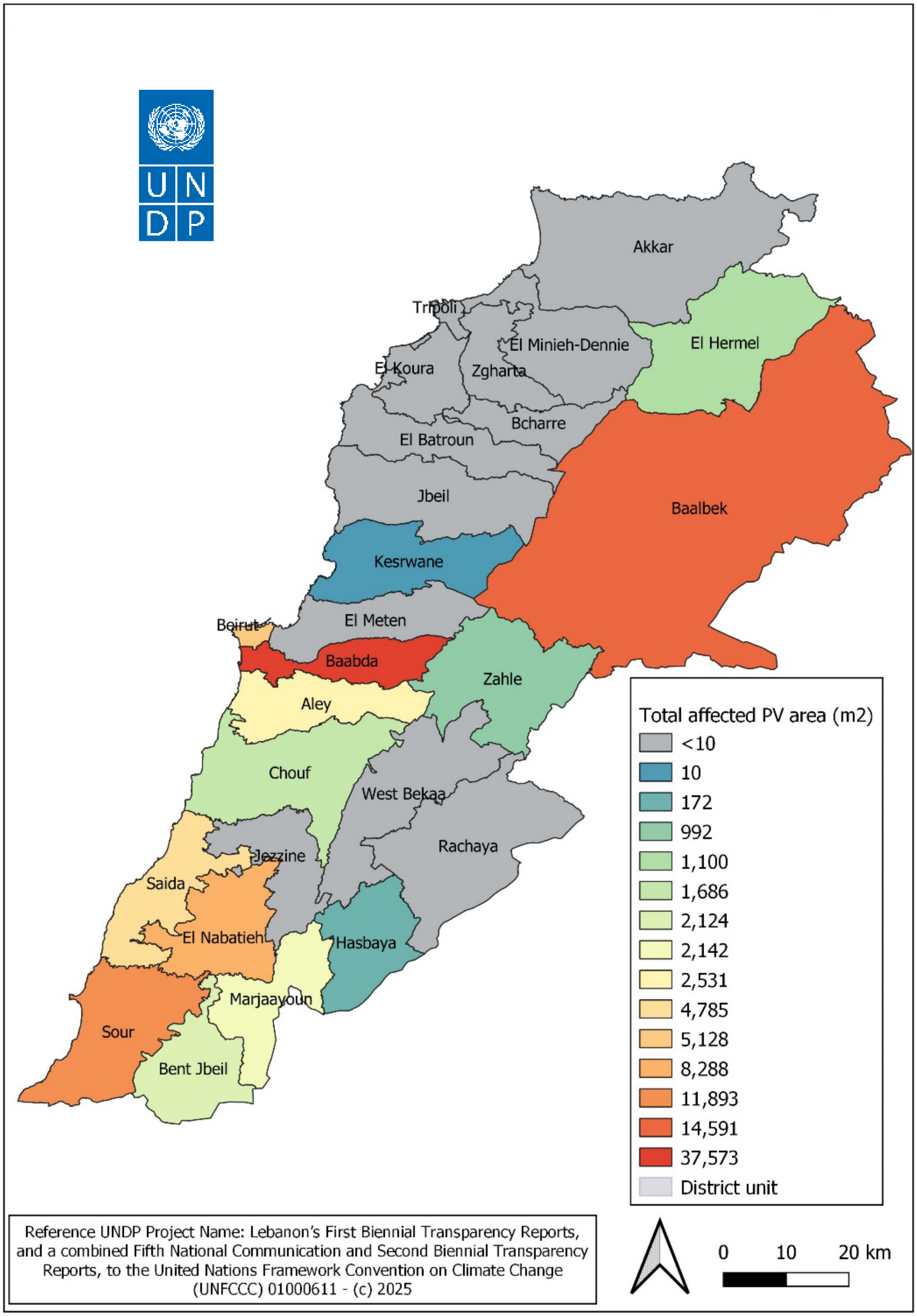

Figure 25: Spatial distribution of damaged PV panels per district across Lebanon

The distribution of affected panels indicated the district of Baabda (mainly covering the southern suburbs of Beirut) as the most affected administrative unit by damaged panels, followed by the districts of Baalbek, Sour and El Nabatiyeh (Figure 26).

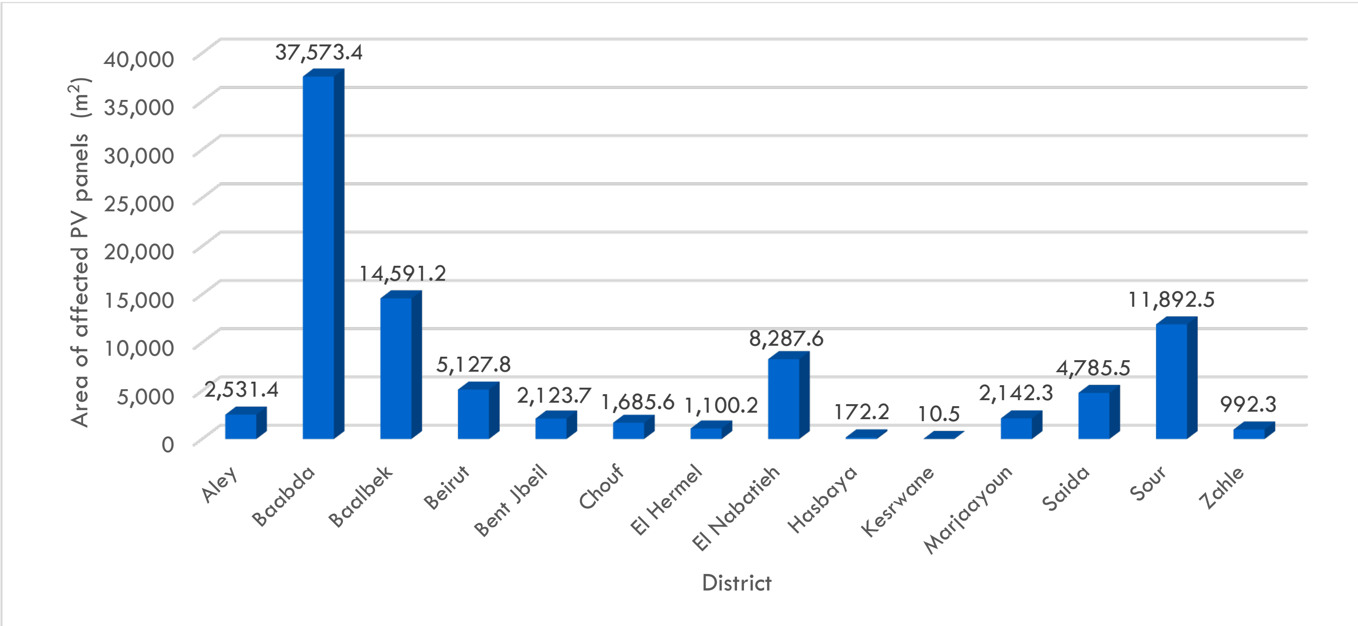

Figure 26: Spatial distribution of affected PV solar panels per district

Damaged PV panels resulted in a total loss of 14.9 MWp in capacity of installed PV panels which directly translated into loss of 21,289.62 MWh in energy generation. The district of Baabda was most affected by losses in capacity as a result of damaged PV panels followed by the districts of Sour and Baalbek (Figure 27). Considering the PV panels which were mapped with a lower confidence an additional loss of 1.77 MWp in capacity is recorded which is directly translated into a loss of 2,528 MWh in energy generation.

It is important to note that the level of damage to PV panels within each districts is not solely dependent on the extent of destruction to buildings but also on the density of installed PV systems on rooftops. Areas with high rooftop PV concentration are more susceptible to significant energy losses, even if structural damage to buildings is partial or moderate. In regions where PV panels are densely installed, even minor blast effects, debris, or shockwaves can impact multiple installations simultaneously, leading to widespread functional losses. Conversely, buildings with minimal PV coverage may experience severe structural damage without corresponding high energy losses.
Overall, the accuracy of mapping damaged PV panels using Sentinel-1 SAR data depends on the sensitivity of backscatter changes to structural damage and debris accumulation. While the adopted approach provided a systematic and scalable assessment, several factors may introduce uncertainties:

- Damage may be overlooked in cases where PV panels remain intact but are rendered non-functional due to wiring or inverter failure, which SAR data cannot detect. Additionally, debris accumulation on panels may not always lead to significant backscatter changes.
- Variability in Sentinel-1 acquisition angles, atmospheric conditions, and differences in surface moisture between pre- and post-war images could affect backscatter consistency.

Despite these limitations, the approach provided a valuable first-order estimation of PV infrastructure damage, helping prioritize recovery efforts.

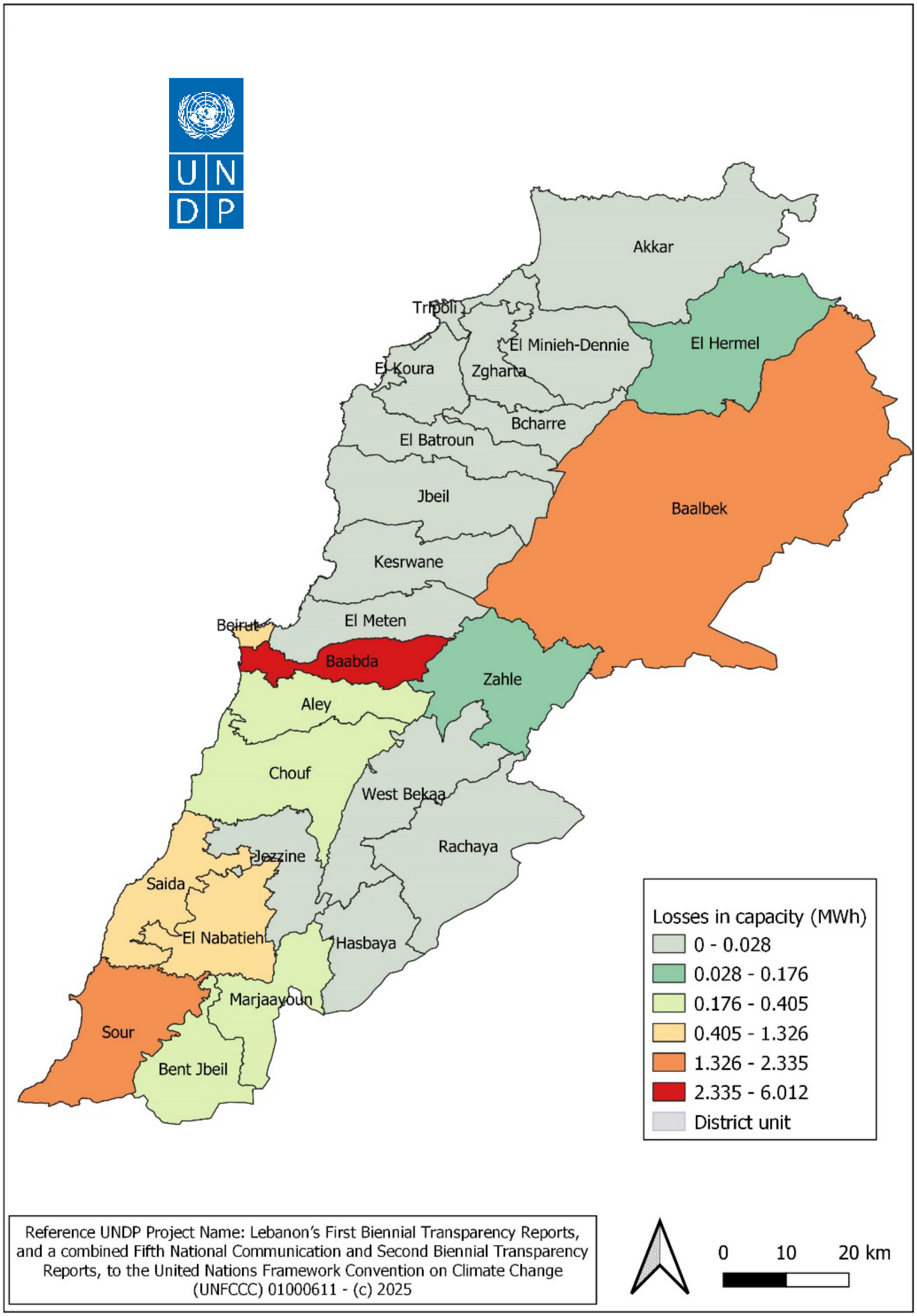

Figure 27: Distribution of losses in capacity from damaged PV solar panels

VII. ADVANCED GEO-SPATIAL ANALYSIS

Topographic characterization of installed solar PV panels

The topographic characterization of installed solar PV panels was conducted by employing the map of identified and mapped solar PV panels (i.e., cumulative area of 2023) in conjunction with a Digital Elevation Model (DEM) of 30 m resolution, a 2013 Land Cover/Land Use (LCLU) map (most recent LCLU map available for Lebanon), and the Global Horizontal Irradiation (GHI) of the World Bank Group's publication of the Global Solar Atlas (GSA) data. This approach allowed for the assessment of the distribution of installed panels in relation to various topographic, land use, and solar irradiation factors. Specifically, the analysis focused on:

- Altitude distribution: The DEM was used to examine the distribution of installed solar PV panels in relation to altitude above sea level, distinguishing between coastal regions and mountainous areas. This provided insights into how elevation and urbanization (e.g., coastal cities versus mountainous towns) might influence the placement and performance of solar installations.
- Land Cover/Land Use: The LCLU map facilitated the assessment of the types of land where solar PV panels have been installed, including agricultural land. This analysis helps to estimate the area of solar PV panels possibly employed for water pumping on agricultural lands, among others.
- Solar resource assessment: The GHI data was utilized to analyze the relationship between solar panel installations and the availability of solar radiation across different regions. This provided a clearer understanding of how solar potential is put to use, providing further information on the efficiency and effectiveness of the installed PV panels.

Through this topographic characterization, valuable insights were gained into the spatial distribution, environmental context, and solar resource availability for solar PV installations, which can inform future planning and development strategies in the region.

On one hand, the total area of solar panels installed on agricultural land (Figure 28) is approximately 540,587.5 m^2 with a high potential of supplying energy for water pumping in agricultural use. On the other hand, about 446,557.9 m^2 of solar panels are installed in industrial/commercial zones knowing that the area could be much larger because detailed maps of industrial/commercial units and zones are still not available in Lebanon.

Figure 28: Imagery subset displaying an installation of two solar PV units on agricultural lands

It was also often observed that areas with private generators in residential areas are installing solar panels on neighboring vacant lands to supplement diesel generators during the day. In general, solar-generated kilowatts are sold for the same price as diesel-generated ones (Figure 29).

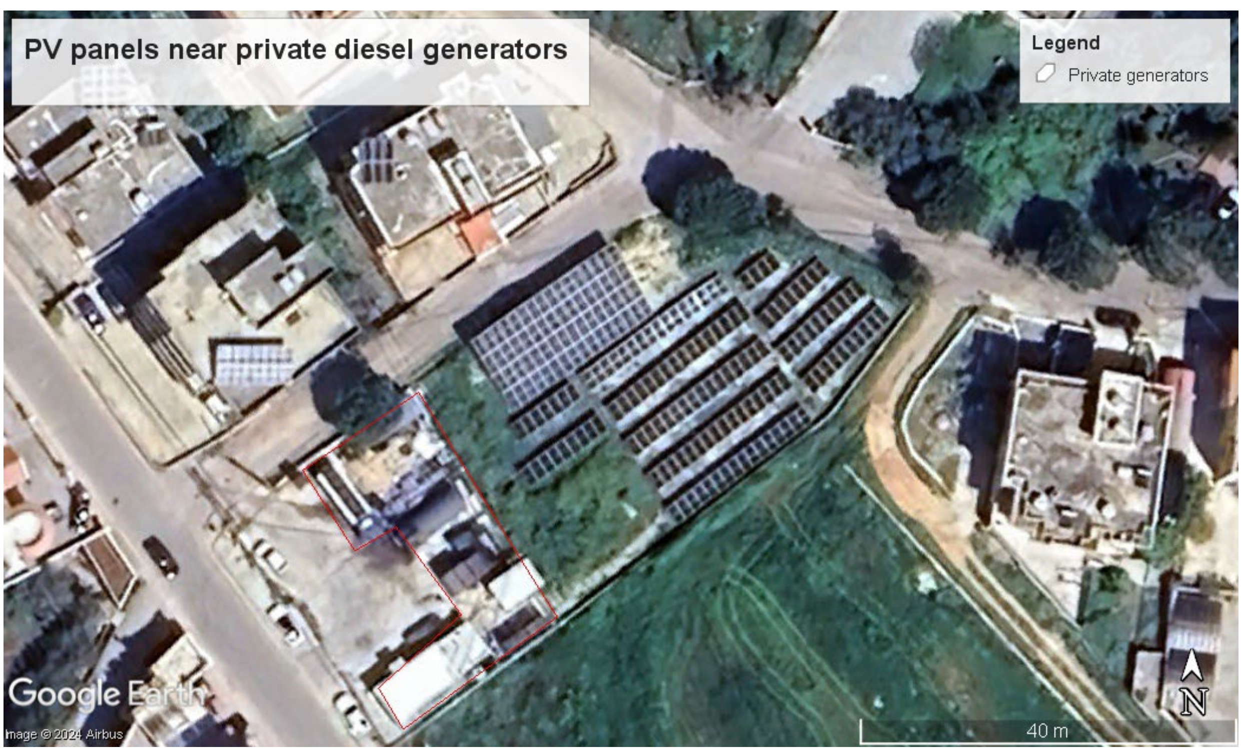

Figure 29: Private diesel generators (highlighted in red) are supplemented with solar-generated kilowatts from PV panels installed on neighboring vacant lands

The distribution of solar PV panels per land type (i.e., agricultural land and industrial/commercial zone) on the national level is provided in Figure 30.

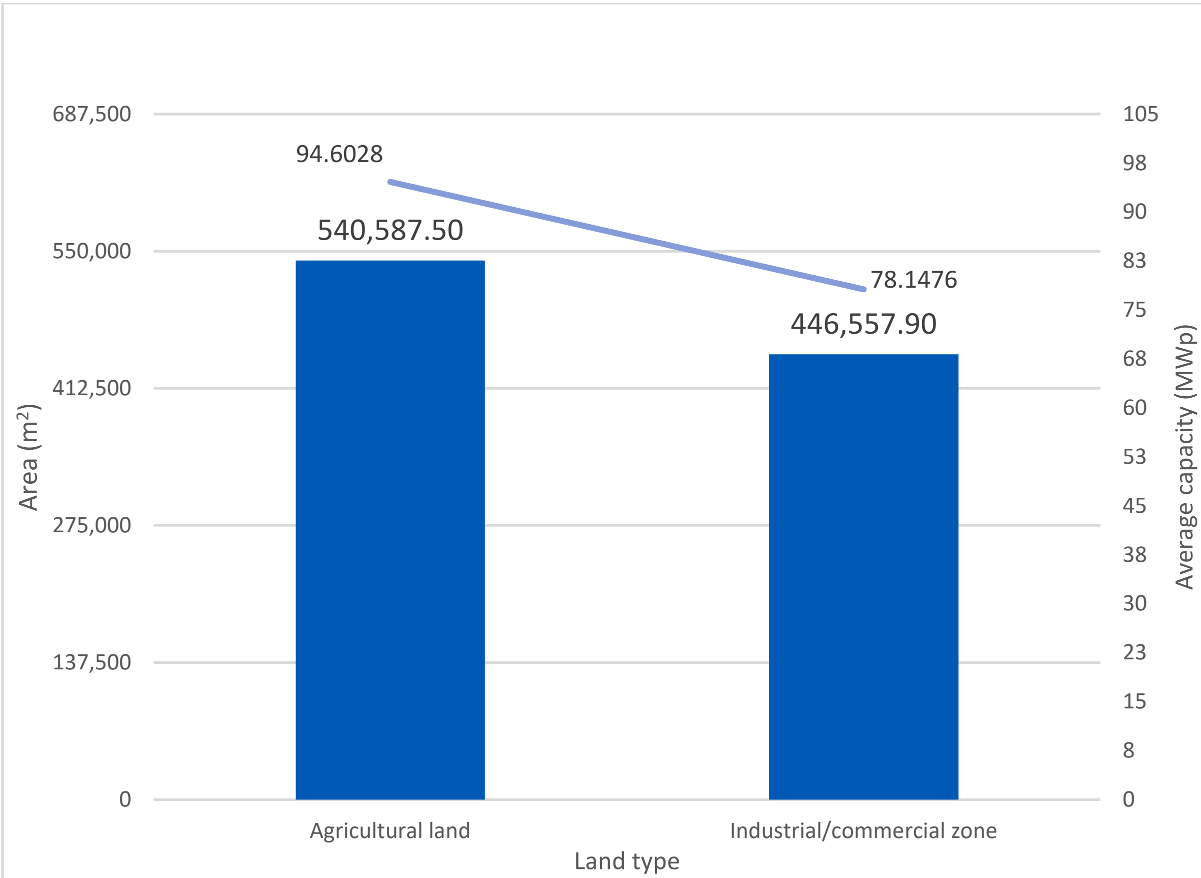

Figure 30: Distribution of solar panels by land type (i.e., agricultural land and industrial/commercial zone)

With reference to the distribution of solar PV panels by elevation range on the national level (Figure 31):

- 0-500 meters: The majority of installations are at this elevation, totaling approximately 3.99 million m^2 (i.e., average capacity of 698.91 MWp).
- 500-1,000 meters: This range has around 1.92 million m^2 of solar panels (i.e., average capacity of 336.71 MWp), showing relatively significant utilization of mid-elevation areas.
- 1,000-1,500 meters: There is a notable presence of solar panels amounting to 934,083.8 m^2 (i.e., average capacity of 163.46 MWp), but the number drops sharply above 1,500 meters, with only about 6,480.5 m^2 (i.e., average capacity of 1.13 MWp).

Lower elevation encompassing most of major coastal cities accommodated the largest areas for solar panel installations mostly due to the presence of high population densities in these areas. The drop in installations above 1,500 meters is mostly related to the presence of lower population densities. In addition, it indicates possible challenges such as harsher weather conditions, limited accessibility, and reduced infrastructure support at higher altitudes.

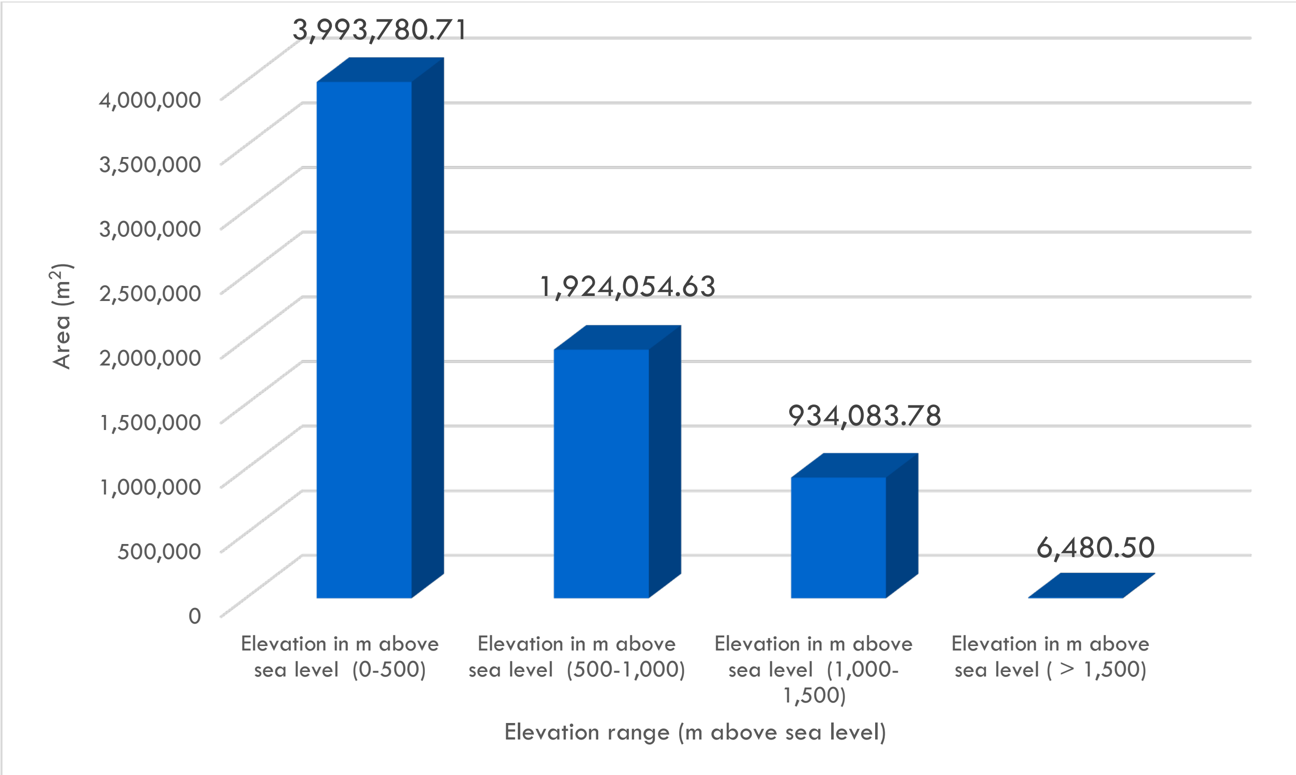

Figure 31: Distribution of solar PV panels by elevation range (National level)

With reference to the distribution of solar panels by the GHI range at the national level (Figure 32):

- <1,400 kW/m^2: Very minimal solar panel installations are found in this range, with only 115.8 m^2.
- 1,400-1,500 kW/m^2 to 1,700-1,800 kW/m^2: Solar panels are present but in moderate quantities, reflecting areas with lower but still viable solar energy potential.
- 1,800-1,900 kW/m^2: This range has the most significant installations, with about 2.6 million m^2, indicating that these regions offer optimal conditions for solar energy production.
- 1,900-2,000 kW/m^2 and 2,000-2,100 kW/m^2: These ranges also show substantial installations, particularly in areas receiving high levels of solar irradiation.

The distribution of solar panels correlates strongly with regions of higher solar irradiation, reflecting a benefit of maximizing energy output and the need to target further areas with the highest potential.

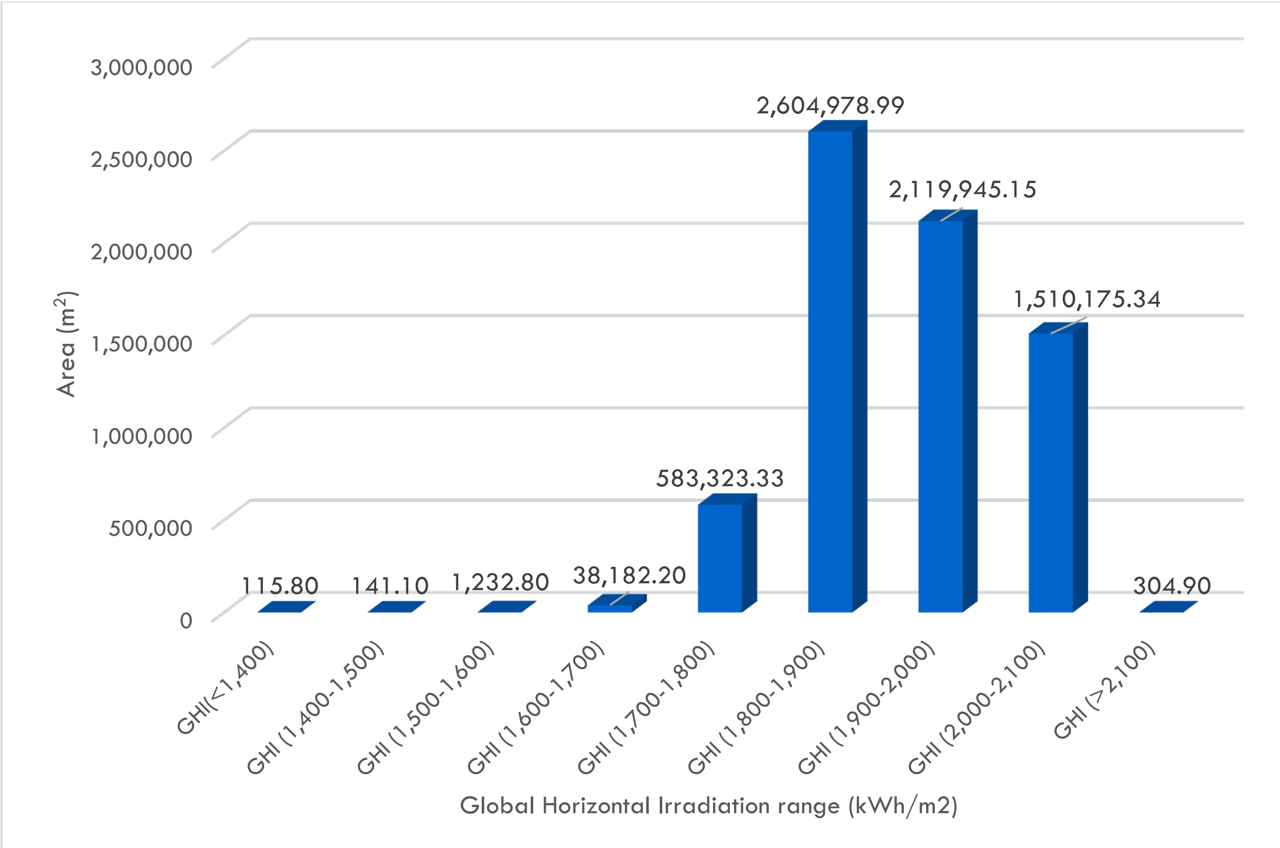

Figure 32: Distribution of PV solar panels per GHI range

The distribution of solar PV panels across various districts, categorized by elevation ranges, reveals several key insights (Figure 33):

- Baalbek has notable solar PV installations concentrated in a high elevation range, specifically between 1,000 and 1,500 meters above sea level.
- Zahle and El Nabatieh exhibit significant solar PV installations in a medium elevation range, between 500 and 1,000 meters above sea level.
- Baabda, Saida, and Sour display substantial PV panel installations predominantly in the lower elevation range (0-500 meters above sea level).
- El Metn, Chouf, and Aley feature diverse elevation profiles with significant PV installations across multiple elevation ranges.

Particularly, districts like Baalbek, with significant installations at higher elevations, may benefit from reduced shading and enhanced solar radiation, making these flat inland areas ideal for solar energy generation. In addition, the presence of the Beqaa Valley between two mountain ranges is likely to reduce cloud cover and increases the potential for solar capture.

Districts such as Zahle and El Nabatieh, with installations in the medium elevation range, could offer a compromise between the challenges of high-altitude installations and the potentially lower solar exposure in lower elevation areas.

Districts like Baabda, Saida, and Sour, where installations are primarily at low elevations, i.e., urban and suburban areas, simplifies the installation process. The dense population and infrastructure in these areas also drive higher demand for distributed solar energy solutions.

The varied elevation profiles in districts such as El Metn, Chouf, and Aley, with considerable PV installations, suggest a better capitalization on multiple elevation ranges. These districts with relatively high population density can optimize solar energy production across different microclimates and topographical conditions.

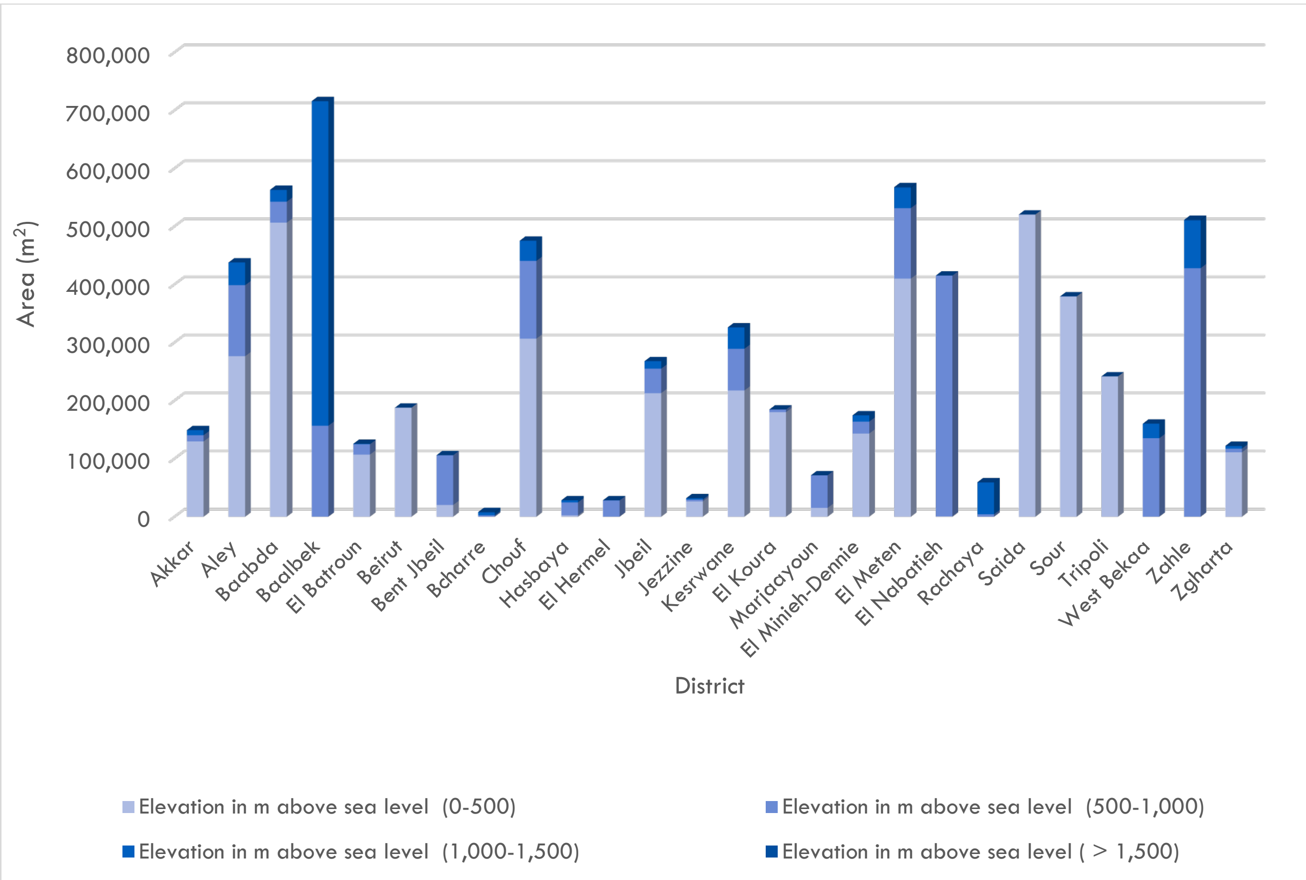

Figure 33: Distribution of solar PV panels per district per elevation range

The distribution of solar PV panels per district by GHI range (kWh/m^2) plots the total area of installed solar PV panels in square meters (m^2) in each district, categorized by the GHI ranges (Figure 34). Districts such as Baalbek and Zahle have the highest concentration of solar PV panels, particularly in areas with GHI values ranging from 2,000-2,100 kWh/m^2 and >2,100 kWh/m^2. This high concentration highlights these two districts as ideal regions for solar energy generation due to their high solar radiation. Districts such as Beirut, Kesrwane, and El Metn have lower GHI values (below 1,800 kWh/m^2), but they still show significant PV installation areas. These regions are characterized by higher population densities and more rooftops available for distributed solar PV installations, even though they do not receive as much solar radiation as further inland districts.

The geographical diversity in GHI and PV deployment suggests that while Lebanon has substantial solar potential, the deployment of solar energy is not yet fully optimized in all its regions, especially those with lower GHI values.

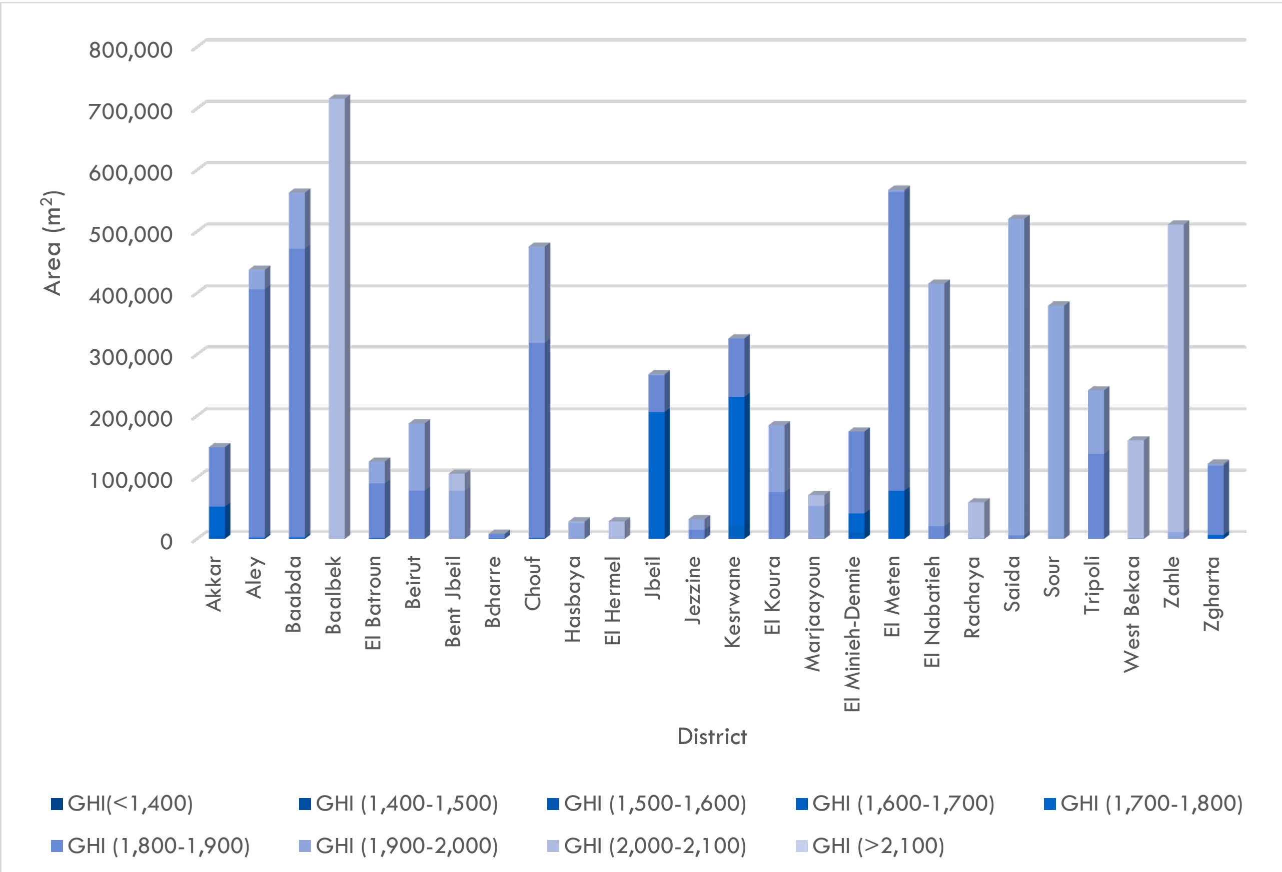

Figure 34: Distribution of solar PV panels per GHI range (kWh/m²)

Availability of solar energy for power generation

The GHI solar resource map in the World Bank Group's publication of the Global Solar Atlas (GSA) was employed to derive the mean estimated solar energy available for power generation at the cadastral unit level in Lebanon. The data represents the average yearly sum of GHI covering a period of 20 years (1999-2018). The solar resource database was calculated using the Solargis model from atmospheric and satellite data with a 30-minute time step. The effects of terrain are considered at nominal spatial resolution of 250 m. GHI is the most important parameter for energy yield calculation and performance assessment of flat-plate PV technologies.

The generated map (Figure 35) provides a detailed visual representation of the distribution of annual GHI across different cadastral units in Lebanon. The southeastern and eastern parts of Lebanon, particularly areas like Baalbek and the Beqaa Valley, are marked in shades of orange and red, indicating high GHI values ranging from 2,006 to 2,135 kWh/m^2. These regions are likely to be the most effective for solar PV installations due to receiving high levels of solar radiation. The central parts of Lebanon, including regions such as Zahle, Chouf, and Aley, have moderate GHI values, ranging from 1,921 to 2,006 kWh/m^2. These areas also present opportunities for solar energy development.

The northern coastal regions and some parts of the north, such as Akkar and the coastal areas near Tripoli, are shown in green and yellow shades, indicating lower GHI values ranging from 1,539 to 1,773 kWh/m^2. While still viable for solar energy, these areas may not be as optimal as the high GHI regions.

The high GHI areas in the southeast and east of Lebanon are ideal for large-scale solar farms. The consistent and strong solar radiation throughout the year makes these regions highly suitable for solar PV installations, potentially leading to higher energy yields and better economic returns.

The central regions, with moderate GHI, are also suitable for solar installations, though the energy yield might be slightly lower than in the high GHI areas. These regions could benefit from both residential rooftop installations and medium-scale solar projects.

The lower GHI regions in the north and along the coast might require more efficient solar technology or hybrid systems to maximize energy production. These areas could also consider integrating solar energy with other renewable sources to balance the lower solar potential.

Strategically, for large-scale solar PV investments, the areas with GHI values above 2,000 kWh/m^2 should be further prioritized for larger PV systems. These regions offer the best environmental conditions for maximizing solar energy production and should be the focus of national and regional solar development plans. A list of cadastral units with a mean GHI above 2,000 kWh/m^2 is provided in **Annex 2. List of cadastral units with a mean GHI above 2000 kWh/m^2** The total area of cadastral units with a mean GHI above 2,000 kWh/m^2 amounted to 416,230 ha (i.e., around 40% of the national territory).

In areas with moderate to low GHI, tailored solutions such as using higher-efficiency panels or hybrid energy systems should be considered. These regions can still contribute significantly to Lebanon's renewable energy mix but may require additional investment in technology or infrastructure.

However, high GHI regions might also require the development of additional infrastructure, such as transmission lines and road access, to fully realize their solar energy potential. Integrating the GHI data with land use planning is essential. Regions with high GHI should be evaluated for their suitability for solar farms, taking into account land availability, existing land use, and potential conflicts with other land uses.

Overall, these results represent a valuable tool for guiding the strategic placement of solar PV installations across Lebanon. While the highest density of PV installation was observed to be mostly in coastal cities (with lower GHI values), by focusing on areas with the highest GHI, Lebanon can maximize the effectiveness of its solar energy investments, contributing significantly to its renewable energy goals. The map also underscores the importance of a regionally differentiated approach, where different strategies are employed depending on the GHI levels and local conditions.

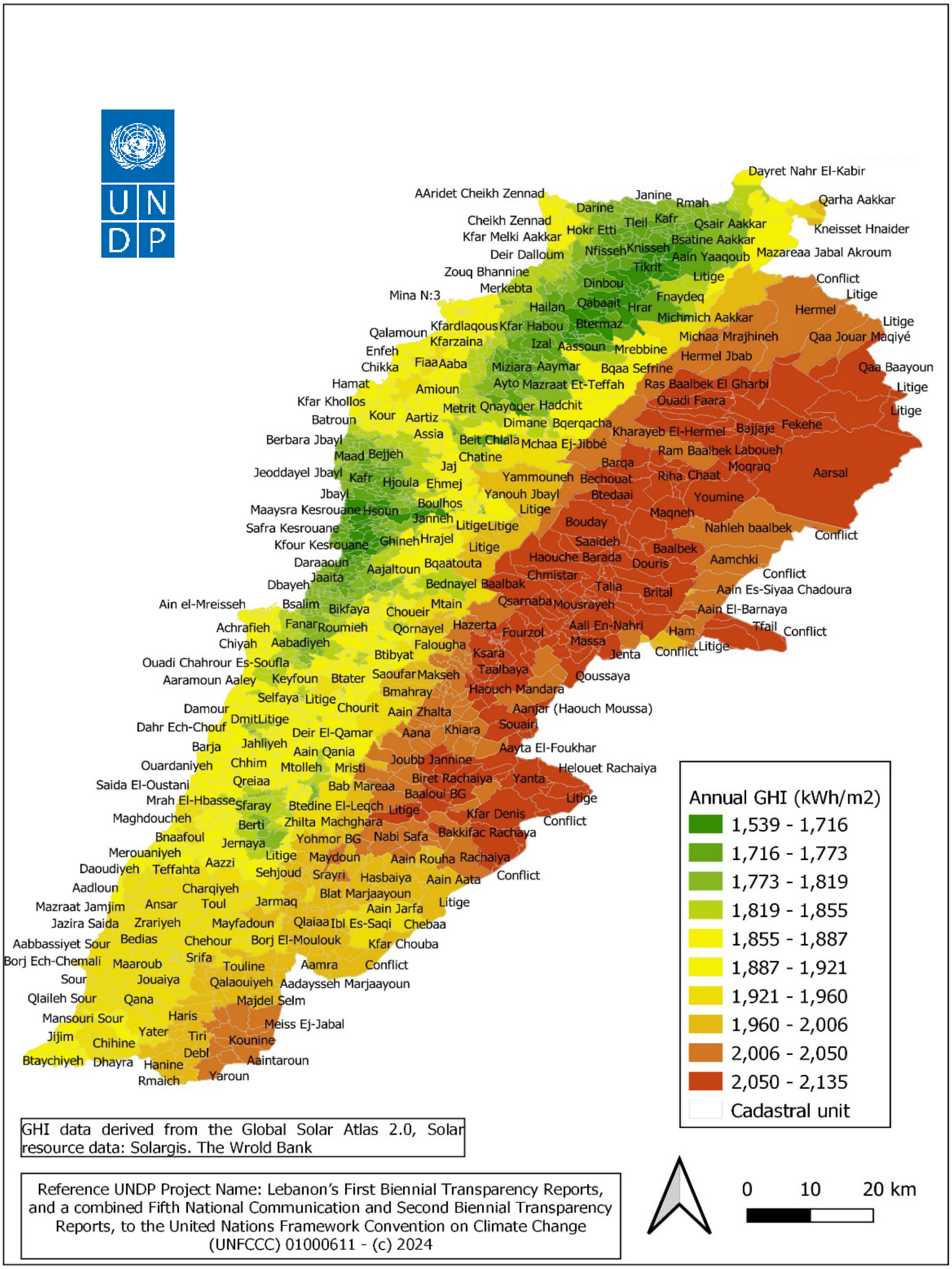

Figure 35: Distribution of mean GHI irradiation at the cadastral unit level

VIII. MAPPING ACCURACY AND UNCERTAINTIES OF RESULTS

Mapping accuracy

The accuracy of the mapping results is subject to several uncertainties that can affect the overall reliability of the data. One major source of uncertainty is the presence of missing tiles in the satellite imagery (especially on the Lebanese Syrian border in the Akkar region), which can lead to incomplete coverage and gaps in the data. These gaps necessitated the use of interpolation and extrapolation techniques to estimate missing values, which can introduce errors, especially if the distribution of PV installation is not uniform. In addition, the mapping process might miss a number of PV units due to various factors such as cloud cover, lack of high-quality images, or obstructions. This can lead to false negatives in the data. There's also the possibility of confusing PV units with other materials that have similar visual characteristics, such as metal roofs, water bodies, and water heating panels (typically excluded counting on their homogeneous color and/or the presence of individual water tanks), among others. This can lead to false positives in the data.

However, the large number of mapped PV units can help dilute these errors. The extensive dataset provides a more comprehensive view, reducing the impact of individual inaccuracies and helping average out anomalies. Despite the uncertainties, the total volume of data points contributes to a more robust and reliable overall analysis. These uncertainties underscore the importance of rigorous data verification and validation processes to enhance the accuracy and reliability of the mapping results. Continuous improvements in remote sensing technology and data processing techniques are essential to mitigate these uncertainties and provide a continuous and clearer picture of the solar energy landscape.

The adopted approach for accuracy assessment of the mapping results approach comprised the use of a confusion matrix by employing both mapped data (classified data) and reference data (ground-truthing data).

In this study, the total number of mapped units amounted to 241,298 units. This number was considered for the estimated total number of samples to be visited in the field. At first, the margin of error and sampling confidence level were determined. On one hand, the margin of error is a measure of the precision of the estimated accuracy of the PV panel mapping. It indicates the range within which the true accuracy lies with a certain level of confidence. In this case, a 5% Margin of Error means that we are willing to accept that the true accuracy of our PV panel mapping could be within ±5% of the estimated value. On the other side, the confidence level indicates the degree of certainty that the true accuracy of our PV panel mapping falls within the margin of error. It is typically expressed as a percentage. It corresponds to a Z-value of 1.96 in statistical calculations.

Accordingly, the following formula was employed to calculate the sampling size:

Equation 2:

$$n = \frac{N \cdot Z^2 \cdot p \cdot (1-p)}{E^2 \cdot (N-1) + Z^2 \cdot p \cdot (1-p)}$$

Where:

- *n = Sample size*
- *N= Population size (241,298)*
- *Z = Z-value (1.96 for 95% confidence level)*
- *p = Estimated proportion (0.5 if unknown)*
- *E = Margin of error (0.05)*

For a total of 241,298 units and a confidence level of 95% with an error margin of 5%, the minimum total sample size that needs to be reached is 384 units. The process involved generating 384 random points (using available GIS algorithms) within previously identified and mapped solar PV panel units (limited to one district, i.e. El Metn district, for ease of practicality during field visits knowing that this district comprises a range of residential, commercial/industrial, urban, and rural areas). In addition, a total of 89 reference points were added to the list of ground-truth data representing sites of completed installations of PV systems until 2023 (with reference to data from various UN agencies). As a result, a total of 473 ground-truth points were considered in this accuracy assessment (Figure 36).

The method resulted in using the confusion matrix to calculate overall accuracy, producer's accuracy, user's accuracy, commission error, and omission error for mapping PV panels versus non-PV panels (Table 3). The results demonstrated a high overall accuracy of 93.4%, indicating that the classification process is reliable for distinguishing between solar PV panels and other surfaces.

The low omission error (2.1%) and commission error (4.9%) for solar PV show that the model rarely misses identifying actual solar PV panels (low omission) and rarely misclassifies other surfaces as solar PV (low commission).

The producer's accuracy (97.9%) reflects that almost all actual solar PV panels are detected by the model, while the user's accuracy (95.1%) shows that most classified solar PV panels are indeed solar PV.

Overall, the classification performs very well in detecting solar PV panels with minimal errors.

Table 3: Mapping accuracy assessment confusion matrix

	Classified	
Reference data	Solar PV	Other
Solar PV	427	9
Other	22	15
Total	**449**	**24**
Overall accuracy (%)		93.4
Omission error Solar PV (%)		2.1
Commission error solar PV (%)		4.9
Producer's accuracy solar PV (%)		97.9
User's accuracy solar PV (%)		95.1

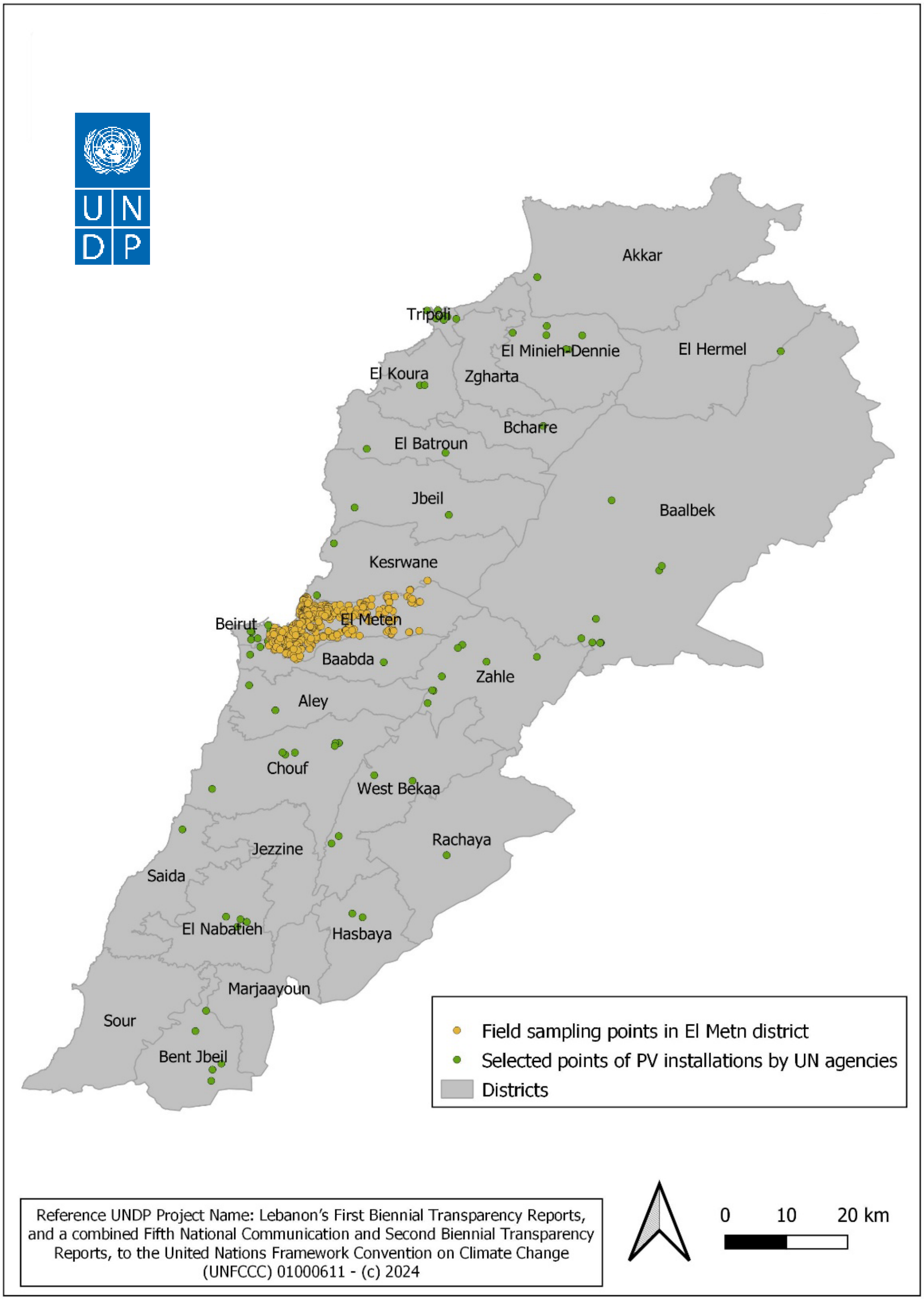

Figure 36: Distribution of ground-truth points

Uncertainties assessment of energy production

Several factors contribute to the overall uncertainty in calculating energy production:

- **Capacity Factor (CF):** The capacity factor for Lebanon adopted in the calculation was 16.33%, while it can vary between 14.24% and 21%.
- **kWp per square meter**: The kWp per square meter varies based on the mapped area:
  - 0.16 kWp/m^2 for 2.69% of the total mapped area.
  - 0.17 kWp/m^2 for 2.47% of the total mapped area.
  - 0.18 kWp/m^2 for 58.6% of the total mapped area.
  - 0.19 kWp/m^2 for 36.24% of the total mapped area.
- Overall, kWp for Lebanon can vary between 0.15 to 0.22.
- **Inclination angle**: An average inclination angle of 21.9° was used in the calculation, while the inclination angle can vary between 12° and 30°.
- **Mapped area and accuracy**: The total mapped area was calculated at 6,858,399.70 m^2, and the mapping accuracy was 93.4%.

Each parameter contributes individual uncertainty to the final energy production calculation:

1. Capacity Factor (CF):

- Adopted value: 16.33%.
- Range: 14.24% to 21%.
- Uncertainty follows a uniform distribution:

$$\sigma_{CF} = \frac{21\% - 14.24\%}{\sqrt{12}} = 1.95\%$$

2. kWp per square meter:

- Weighted average (kWp) based on area distribution:

kWp_{avg} =0.16×0.0269+0.17×0.0247+0.18×0.586+0.19×0.3624=0.181

- Uncertainty in kWp:

$$\sigma_{kWp} = \frac{0.22 - 0.15}{\sqrt{12}} = 0.0202$$

3. Inclination angle:

- Adopted value: 21.9°.
- Range: 12° to 30°.
- Uncertainty in inclination angle:

$$\sigma_\theta = \frac{30^\circ - 12^\circ}{\sqrt{12}} = 5.20^\circ$$

4. Mapping accuracy:

- Mapping accuracy: 93.4%.
- Mapping uncertainty:

$$\sigma_{\mathbf{mapping}} = 100\% - 93.4\% = 6.6\%$$

To propagate the uncertainties through the energy production formula, the following method for combining uncertainties in multiplicative models was employed:

$$\frac{\sigma_E}{E} = \sqrt{\left(\frac{\sigma_{CF}}{CF}\right)^2 + \left(\frac{\sigma_{kWp}}{kWp_{\text{avg}}}\right)^2 + \left(\frac{\sigma_\theta}{\theta}\right)^2 + \left(\frac{\sigma_{\text{mapping}}}{\text{mapping accuracy}}\right)^2}$$

Where:

σ_E is the uncertainty in total energy production.

E is the total energy production (1.79 TWh).

σ_{CF}, σ_{kWp}, σ_θ ,$\sigma_{mapping}$ are the uncertainties in each parameter.

To estimate the combined uncertainty, a Monte Carlo simulation was implemented:

- Random sampling: Sample from uniform distributions for each parameter (capacity factor, kWp per square meter, inclination angle, and mapping accuracy).
- Simulation runs: Perform 10,000 iterations, where each iteration recalculates the total energy production based on randomly sampled values.

- Output analysis: Calculate the mean energy production, standard deviation, and 95% confidence interval from the simulation results.

The Monte Carlo simulation results comprised the following:

- Mean Energy Production: 1.89 TWh.
- Standard Deviation (Uncertainty): 0.30 TWh.
- 95% Confidence Interval:
    - Lower Bound: 1.37 TWh.
    - Upper Bound: 2.50 TWh.

Below is a histogram of the Monte Carlo simulation results, showing the frequency of energy production estimates (Figure 37). The red line indicates the mean energy production, and the green lines show the lower and upper bounds of the 95% confidence interval.

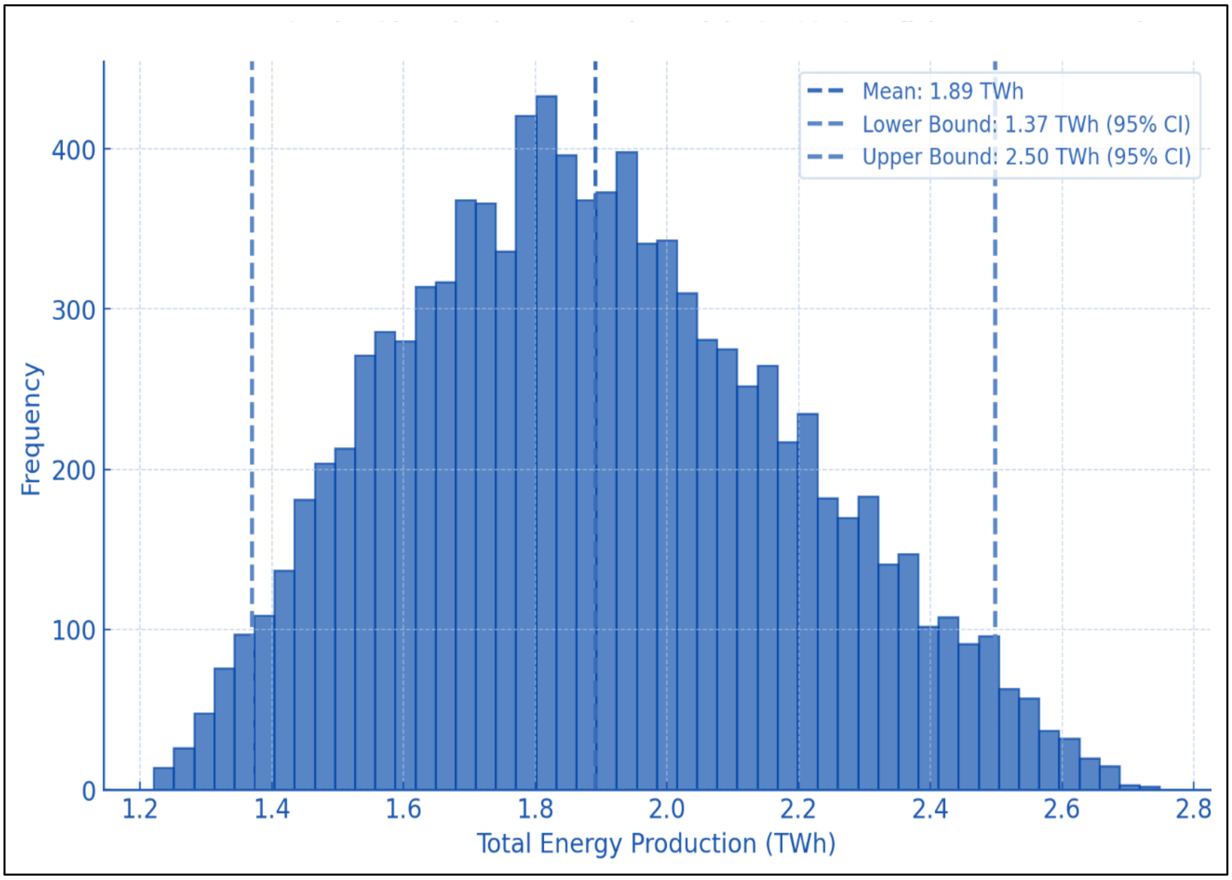

Figure 37: Monte Carlo simulation results (with 95% confidence interval)

The mean energy production is estimated at 1.89 TWh, slightly higher than the original calculation of 1.79 TWh due to the probabilistic approach. The uncertainty (standard deviation) is 0.30 TWh. The 95% confidence interval, ranging from 1.37 TWh to 2.50 TWh, provides a robust estimate of possible energy production given the uncertainties in capacity factor, kWp per square meter, inclination angle, and mapping accuracy.

IX. CONCLUSION

The following section provides general concluding remarks about functionality and effectiveness of installed solar PV panels, geographical and topographical challenges, solar irradiation variability, infrastructure and resource allocation, and policy and regulatory barriers.

Functionality and effectiveness

In terms of energy generation, the increase in installed capacity directly translated into higher energy generation:

- 2020: 42,273 MWh (versus 132,677 MWh as estimated by LCEC)
- 2021: 83,448 MWh (versus 308,887 MWh as estimated by LCEC)
- 2022: 1,118,349 MWh (versus 1,262,343 MWh as estimated by LCEC)
- 2023: 1,793,824 MWh (no estimation is available from LCEC for 2023 until present)

The discrepancies between the results derived from mapping PV solar panels and the LCEC reported numbers could be attributed to several key factors:

- Mapping PV solar panels: This method likely involves the use of satellite imagery, high-resolution spatial data, and other remote sensing techniques to identify installed PV units. The results heavily depend on the accuracy of the data, satellite coverage, and the precision of the algorithms used to detect panels. It also measures actual physical installations, not potential installations or planned projects.
- LCEC data: LCEC data is mostly based on reports from installers, manufacturers, and grid operators. Their numbers may also include planned or proposed projects, capacity estimates based on sales of solar panels or permits issued, or general market studies. This data may overestimate installations by including installations that haven't been completed.
- LCEC's MWh estimates may be based on specific assumptions about solar capacity factors that might differ from the factors employed through mapping.

Overall, this growth reflects not only an increase in installed PV panels, but also a substantial enhancement in the functionality and effectiveness of the solar energy systems.

With regard to geographical distribution and effectiveness, the district of Baalbek notably had the highest cumulative capacity by 2023, with significant solar PV installations distributed across areas of high GHI. This district's effectiveness is likely enhanced due to reduced shading and higher solar radiation at these altitudes. Nationally, most installations (around 3.99 million m^2) were found at lower elevations (0-500 meters), primarily in coastal regions. These areas are advantageous due to high population densities and infrastructure availability, facilitating the effective use of solar energy systems. Yet, the areas with the highest GHI (2,000-2,100 kWh/m^2) have not witnessed substantial solar PV installations, with the exception of the Baalbek district; therefore, further planning is needed to strategically place solar PV systems to maximize functionality and effectiveness.

A significant portion of solar PV panels amounting to 540,587.5 m^2 (i.e., average of 94.6 MWp) was installed on agricultural land, indicating a potential dual-use functionality where solar energy supports both power generation and agricultural activities (e.g., water pumping). Additionally, 446,557.9 m^2 of panels (i.e., average of 78.15MWp) were installed in industrial/commercial zones, which are likely contributing efficiently to energy needs in these high-demand areas and reducing production/service costs.

Overall, the data indicates robust growth in solar energy capacity and energy generation, with some installations strategically placed in regions with high solar potential and in areas that offer dual benefits (energy supply to a large number of population and high solar irradiation).

Geographical, environmental, and physical challenges

Some of the geographical and environmental challenges include:

- **High-altitude regions**: There is a sharp drop in PV installations above 1,500 meters, with approximately only 6,480.5 m^2 installed. The challenges in these areas could include harsh weather conditions, limited accessibility, and reduced infrastructure support, all of which could hamper efficiency and increase installation costs.
- **Remote and less accessible areas**: Some districts, especially those with lower population densities or those in mountainous regions, might face logistical installation challenges.
- **Regions with lower GHI**: Areas like Akkar and coastal regions near Tripoli, with GHI values ranging from 1,539 to 1,773 kWh/m^2, have lower solar energy potential. The efficiency of PV systems in these areas might be lower, requiring more advanced or hybrid systems to optimize energy production (e.g., use of wind energy in Akkar).
- **Infrastructure gaps**: High GHI regions, which are ideal for large-scale solar farms, could still require significant infrastructure development, such as transmission lines and road access, to fully exploit their solar potential. Without this infrastructure, the efficiency and scalability of solar energy systems could be severely limited.
- **Resource allocation**: The concentration of solar installations in coastal areas (lower GHI but higher population density) reflects how resource allocation is skewed towards areas with existing infrastructure and high population densities rather than those with the highest solar potential. This could limit the overall efficiency and effectiveness of the solar energy strategy.

Land use policy and regulatory barriers

- **Land-Use conflicts**: The future deployment of solar panels on agricultural land, while beneficial in some respects, might also lead to conflicts with food production and land use policies. Balancing these competing interests is crucial for sustainable development.
- **Regulatory and planning challenges**: The lack of comprehensive land-use planning that integrates solar potential data with other land use priorities could hinder the optimal deployment of solar energy systems. Without clear policies and incentives, regions with high solar potential might remain underutilized.

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ANNEXES

ANNEX 1. Detailed spatial distribution of assessed solar PV unit installations across various districts in Lebanon

Mapping results of maximum area (i.e., inclination angle of 21.9 degree) of PV units per district

	Confirmed Number of PV units (cumulative)	Rectified mapped area 2020 (m²)	Rectified mapped area 2021 (m²)	Rectified mapped area 2022 (m²)	Rectified mapped area 2023 (m²)	Total
Akkar	9,673	1,986.23	2,016.86	59,232.32	85,843.96	149,079.37
Aley	19,362	15,065.53	9,937.39	368,120.57	44,647.18	437,770.67
Baabda	11,897	480.33	5,161.77	434,664.84	122,746.10	563,053.04
Baalbek	27,671	8,897.98	8,377.79	102,919.38	595,677.84	715,873.00
Batroun	4,619	3,073.45	1,155.15	88,660.48	32,729.24	125,618.33
Bcharreh	465	128.67	130.65	3,837.13	4,058.70	8,155.15
Beirut	3,271	10,918.94	4,792.18	134,540.45	37,486.78	187,738.36
Bint Jbeil	6,066	236.64	881.60	87,878.86	16,933.65	105,930.74
Chouf	16,702	5,152.78	141.24	357,350.89	112,627.30	475,272.21
Hasbaya	1,226	620.20	800.87	18,324.20	8,622.06	28,367.33
Hermel	878	156.15	1,413.16	18,222.12	8,575.42	28,366.85
Jbeil	6,233	46,101.59	589.26	22,176.55	198,964.57	267,831.97
Jezzine	896	27.86	465.56	21,316.11	10,142.37	31,951.90
Kesrouane	8,515	18,303.81	17,072.98	146,184.03	144,413.84	325,974.66
Koura	8,411	1,571.86	57,027.17	18,495.31	107,549.66	184,644.00
Marjaioun	4,135	1,571.86	1,596.09	46,875.01	21,289.04	71,332.00
Metn	14,318	12,762.95	32,843.44	377,069.89	144,932.08	567,608.36
Minnieh-Donniyeh	9,331	7.59	7.47	46,382.93	128,163.63	174,561.61
Nabatiyeh	17,306	15,676.79	3,704.60	302,030.73	93,752.40	415,164.53
Rachaya	2,671	1,297.50	1,317.50	38,693.30	18,037.87	59,346.18
Saida	17,965	491.01	270.05	516,358.94	3,253.05	520,373.05
Sour	14,038	2,509.52	3,237.24	173,583.75	200,015.13	379,345.64
Tripoli	9,680	1,766.78	2,378.88	134,360.21	103,049.74	241,555.61

West Beqaa	6,291	1,720.96	8,354.65	99,473.43	50,648.86	160,197.91
Zahleh	14,843	33,819.76	4,757.40	353,740.31	118,889.04	511,206.50
Zgharta	4,835	346.32	883.92	48,677.00	72,173.49	122,080.73

Mapping results of average area (i.e., inclination angle of 21.9 degree) of PV units per district

	Confirmed Number of PV units (cumulative)	Rectified mapped area 2020 (m2)	Rectified mapped area 2021 (m2)	Rectified mapped area 2022 (m2)	Rectified mapped area 2023 (m2)	Total
Akkar	9,673	1,986.23	2,016.86	59,232.32	85,843.96	149,079.37
Aley	19,362	15,065.53	9,937.39	368,120.57	44,647.18	437,770.67
Baabda	11,897	480.33	5,161.77	434,664.84	122,746.10	563,053.04
Baalbek	27,671	8,897.98	8,377.79	102,919.38	595,677.84	715,873.00
Batroun	4,619	3,073.45	1,155.15	88,660.48	32,729.24	125,618.33
Bcharreh	465	128.67	130.65	3,837.13	4,058.70	8,155.15
Beirut	3,271	10,918.94	4,792.18	134,540.45	37,486.78	187,738.36
Bint Jbeil	6,066	236.64	881.60	87,878.86	16,933.65	105,930.74
Chouf	16,702	5,152.78	141.24	357,350.89	112,627.30	475,272.21
Hasbaya	1,226	620.20	800.87	18,324.20	8,622.06	28,367.33
Hermel	878	156.15	1,413.16	18,222.12	8,575.42	28,366.85
Jbeil	6,323	46,101.59	589.26	22,176.55	198,964.57	267,831.97
Jezzine	896	27.86	465.56	21,316.11	10,142.37	31,951.90
Kesrouane	8,515	18,303.81	17,072.98	146,184.03	144,413.84	325,974.66
Koura	8,411	1,571.86	57,027.17	18,495.31	107,549.66	184,644.00
Marjaioun	4,135	1,571.86	1,596.09	46,875.01	21,289.04	71,332.00
Metn	14,318	12,762.95	32,843.44	377,069.89	144,932.08	567,608.36
Minnieh-Donniyeh	9,331	7.59	7.47	46,382.93	128,163.63	174,561.61
Nabatiyeh	17,306	15,676.79	3,704.60	302,030.73	93,752.40	415,164.53
Rachaya	2,671	1,297.50	1,317.50	38,693.30	18,037.87	59,346.18
Saida	17,965	491.01	270.05	516,358.94	3,253.05	520,373.05

	Confirmed Number of PV units (cumulative)	Rectified mapped area 2020 (m2)	Rectified mapped area 2021 (m2)	Rectified mapped area 2022 (m2)	Rectified mapped area 2023 (m2)	Total
Sour	14,038	2,509.52	3,237.24	173,583.75	200,015.13	379,345.64
Tripoli	9,680	1,766.78	2,378.88	134,360.21	103,049.74	241,555.61
West Beqaa	6,291	1,720.96	8,354.65	99,473.43	50,648.86	160,197.91
Zahleh	14,843	33,819.76	4,757.40	353,740.31	118,889.04	511,206.50
Zgharta	4,835	346.32	883.92	48,677.00	72,173.49	122,080.73
Total	**241,298**					**6858,399.70**

Mapping results of minimum area (i.e., inclination angle of 12 degree) of PV units per district

	Confirmed Number of PV units (cumulative)	Rectified mapped area 2020 (m^2)	Rectified mapped area 2021 (m^2)	Rectified mapped area 2022 (m^2)	Rectified mapped area 2023 (m^2)	Total
Akkar	9,673	1,884.69	1,913.74	56,204.08	81,455.21	141,457.72
Aley	19,362	14,295.31	9,429.34	349,300.50	42,364.60	415,389.76
Baabda	11,897	455.78	4,897.88	412,442.71	116,470.73	534,267.10
Baalbek	27,671	8,443.07	7,949.48	97,657.66	565,223.96	679,274.18
Batroun	4,619	2,916.32	1,096.10	84,127.74	31,055.97	119,196.12
Bcharreh	465	122.09	123.97	3,640.96	3,851.20	7,738.22
Beirut	3,271	10,360.71	4,547.18	127,662.11	35,570.28	178,140.28
Bint Jbeil	6,066	224.54	836.53	83,386.07	16,067.92	100,515.06
Chouf	16,702	4,889.34	134.02	339,081.41	106,869.26	450,974.04
Hasbaya	1,226	588.49	759.92	17,387.38	8,181.26	26,917.06
Hermel	878	148.17	1,340.91	17,290.52	8,137.00	26,916.61
Jbeil	6,323	43,744.66	559.13	21,042.78	188,792.56	254,139.13
Jezzine	896	26.43	441.76	20,226.33	9,623.85	30,318.36
Kesrouane	8,515	17,368.03	16,200.13	138,710.41	137,030.72	309,309.29
Koura	8,411	1,491.50	54,111.67	17,549.74	102,051.21	175,204.12
Marjaioun	4,135	1,491.50	1,514.49	44,478.54	20,200.65	67,685.17

Metn	14,318	12,110.45	31,164.33	357,792.29	137,522.46	538,589.53
Minnieh-Donniyeh	9,331	7.20	7.09	44,011.61	121,611.30	165,637.19
Nabatiyeh	17,306	14,875.32	3,515.21	286,589.48	88,959.33	393,939.35
Rachaya	2,671	1,231.17	1,250.15	36,715.12	17,115.69	56,312.12
Saida	17,965	465.91	256.24	489,960.22	3,086.74	493,769.11
Sour	14,038	2,381.22	3,071.74	164,709.32	189,789.41	359,951.69
Tripoli	9,680	1,676.46	2,257.26	127,491.08	97,781.35	229,206.14
West Beqaa	6,291	1,632.97	7,927.52	94,387.88	48,059.45	152,007.83
Zahleh	14,843	32,090.73	4,514.17	335,655.43	112,810.87	485,071.20
Zgharta	4,835	328.61	838.73	46,188.40	68,483.64	115,839.38
Total	**241,298**					**6507,765.77**

ANNEX 2. List of cadastral units with a mean GHI above 2000 kWh/m^2

Cadastral units	District	Mohafazat	Mean GHI (kWh/m^2)	Area (ha)
Tfail	Baalbek	Baalbek-El Hermel	2,110.18	2,956.65
Aain Ej-Jaouz Baalbek	Baalbek	Baalbek-El Hermel	2,098.43	2,596.46
Selsata (Mazraat Deir El-Aachaiyer)	Rachaya	Beqaa	2,097.99	253.92
Deir El-Aachayer	Rachaya	Beqaa	2,095.81	2,302.64
Helouet Rachaiya	Rachaya	Beqaa	2,095.71	1,825.57
Fekehe	Baalbek	Baalbek-El Hermel	2,085.65	5,904.43
Hizzine	Baalbek	Baalbek-El Hermel	2,083.56	447.65
Kfar Dabach	Baalbek	Baalbek-El Hermel	2,083.09	511.50
Haouch Snaid	Baalbek	Baalbek-El Hermel	2,083.00	884.68
Talia	Baalbek	Baalbek-El Hermel	2,082.75	768.97
Haouch En-Nabi	Baalbek	Baalbek-El Hermel	2,082.38	176.45
Khodr Baalbek	Baalbek	Baalbek-El Hermel	2,082.25	700.68
Majdaloun	Baalbek	Baalbek-El Hermel	2,081.69	1,038.30
Yanta	Rachaya	Beqaa	2,081.46	3,375.54
Taibet Baalbek	Baalbek	Baalbek-El Hermel	2,081.43	1,750.43
Chaat	Baalbek	Baalbek-El Hermel	2,080.08	2,748.63
Nabi Chit	Baalbek	Baalbek-El Hermel	2,079.72	1,772.14
Zabboud	Baalbek	Baalbek-El Hermel	2,079.38	787.43
Mousrayeh	Baalbek	Baalbek-El Hermel	2,079.00	261.14
Haouche Barada	Baalbek	Baalbek-El Hermel	2,078.86	609.47
Serraaine Et-Tahta	Baalbek	Baalbek-El Hermel	2,078.83	2,355.06
Haouch Er-Rafqa	Baalbek	Baalbek-El Hermel	2,078.42	571.15
Sbouba	Baalbek	Baalbek-El Hermel	2,078.36	574.13
Ras Baalbek Ech-Charqi	Baalbek	Baalbek-El Hermel	2,078.00	5,790.24
Chmistar	Baalbek	Baalbek-El Hermel	2,077.96	2,427.20
Maqneh	Baalbek	Baalbek-El Hermel	2,077.84	2,878.23
Beit Chama	Baalbek	Baalbek-El Hermel	2,077.76	572.16
Bajjaje	Baalbek	Baalbek-El Hermel	2,077.46	632.18
Ras Baalbek Es-Sahel	Baalbek	Baalbek-El Hermel	2,077.31	6,764.65

Cadastral units	District	Mohafazat	Mean GHI (kWh/m^2)	Area (ha)
Haouch Tall Safiyeh	Baalbek	Baalbek-El Hermel	2,077.14	504.88
Aadous	Baalbek	Baalbek-El Hermel	2,076.77	197.89
Kharayeb El-Hermel	Baalbek	Baalbek-El Hermel	2,076.55	554.95
Qsarnaba	Baalbek	Baalbek-El Hermel	2,076.46	651.07
Kfar Dane	Baalbek	Baalbek-El Hermel	2,076.43	1,142.09
Haouch El-Ghanam	Zahle	Beqaa	2,076.38	276.03
Qarha Baalbek	Baalbek	Baalbek-El Hermel	2,076.33	415.37
Hadath Baalbek	Baalbek	Baalbek-El Hermel	2,076.10	3,095.29
Ras Baalbek Ouadi Faara	El Hermel	Baalbek-El Hermel	2,075.61	1,936.79
Douris	Baalbek	Baalbek-El Hermel	2,075.51	1,927.38
Haouch El-Dehab	Baalbek	Baalbek-El Hermel	2,075.13	487.50
Riha	Baalbek	Baalbek-El Hermel	2,074.69	1,340.98
Saaideh	Baalbek	Baalbek-El Hermel	2,074.41	593.09
Nabi Osmane	Baalbek	Baalbek-El Hermel	2,074.20	1,067.78
Iaat	Baalbek	Baalbek-El Hermel	2,074.00	2,845.37
Temnine Et-Tahta	Baalbek	Baalbek-El Hermel	2,073.91	743.23
Aali En-Nahri	Zahle	Beqaa	2,073.76	419.59
Raait	Zahle	Beqaa	2,073.37	530.68
Jebaa	Baalbek	Baalbek-El Hermel	2,073.36	664.80
Nasriyet Rizk	Zahle	Beqaa	2,073.10	724.05
Aain Baalbek	Baalbek	Baalbek-El Hermel	2,073.04	878.19
Temnine El-Faouqa	Baalbek	Baalbek-El Hermel	2,072.70	1,094.42
Kneisset Baalbek	Baalbek	Baalbek-El Hermel	2,072.57	1,752.96
Baalbek	Baalbek	Baalbek-El Hermel	2,072.49	3,742.54
Laboueh	Baalbek	Baalbek-El Hermel	2,071.79	2,281.88
Ouadi El-Aaoss	Baalbek	Baalbek-El Hermel	2,071.49	1,275.66
Taraiya	Baalbek	Baalbek-El Hermel	2,070.07	5,114.89
Massa	Zahle	Beqaa	2,069.20	702.60
Riyaq	Zahle	Beqaa	2,069.18	332.03
Nabi Ayla	Zahle	Beqaa	2,069.03	415.20

Cadastral units	District	Mohafazat	Mean GHI (kWh/m²)	Area (ha)
Ablah	Zahle	Beqaa	2,068.43	598.51
Niha Zahleh	Zahle	Beqaa	2,068.18	970.54
Harabta	Baalbek	Baalbek-El Hermel	2,068.18	6,633.58
Moqraq	Baalbek	Baalbek-El Hermel	2,068.09	1,492.49
Maaysra El-Hermel	El Hermel	Baalbek-El Hermel	2,067.91	605.08
Haouch El-Aamara	Zahle	Beqaa	2,067.74	95.02
Bakka	Rachaya	Beqaa	2,067.63	617.47
Bechouat	Baalbek	Baalbek-El Hermel	2,067.19	1,432.75
Kfar Qouq	Rachaya	Beqaa	2,067.15	5,544.45
Ram Baalbek	Baalbek	Baalbek-El Hermel	2,066.80	701.77
Aayta El-Foukhar	Rachaya	Beqaa	2,065.88	2,582.07
Deir El-Ahmar	Baalbek	Baalbek-El Hermel	2,065.84	4,146.86
Haouch Hala	Zahle	Beqaa	2,065.58	571.85
Chlifa	Baalbek	Baalbek-El Hermel	2,065.13	1,725.63
Qaa Baalbek	Baalbek	Baalbek-El Hermel	2,064.18	1,291.65
Btedaai	Baalbek	Baalbek-El Hermel	2,063.99	1,298.83
Deir Mar Maroun Baalbek	Baalbek	Baalbek-El Hermel	2,063.74	617.54
Fourzol	Zahle	Beqaa	2,063.47	1,695.21
Khreibet Baalbek	Baalbek	Baalbek-El Hermel	2,063.44	2,221.21
Zahleh El-Maallaqa	Zahle	Beqaa	2,063.34	61.67
Halbata	Baalbek	Baalbek-El Hermel	2,063.31	1,651.40
Haour Taala	Baalbek	Baalbek-El Hermel	2,062.95	2,294.27
Zahleh El-Midane	Zahle	Beqaa	2,062.75	30.23
Zahleh Haouch El-Oumara	Zahle	Beqaa	2,062.47	143.21
Hoshmosh	Zahle	Beqaa	2,061.42	706.91
Zahleh Maallaqa Aradi	Zahle	Beqaa	2,060.32	1,984.29
Bouday	Baalbek	Baalbek-El Hermel	2,060.16	5,988.70
Zahleh Haouch El-Oumara Aradi	Zahle	Beqaa	2,060.04	1,448.22
Zahleh Mar Antonios	Zahle	Beqaa	2,059.86	3.27
Rafid Rachaiya	Rachaya	Beqaa	2,059.77	800.22
Ouadi Faara	El Hermel	Baalbek-El Hermel	2,059.61	2,693.71

Cadastral units	District	Mohafazat	Mean GHI (kWh/m^2)	Area (ha)
Youmine	Baalbek	Baalbek-El Hermel	2,059.24	7,759.70
Zahleh Mar Gerges	Zahle	Beqaa	2,059.16	19.36
Zahleh Saydet En-Najat	Zahle	Beqaa	2,059.14	15.61
ZahlehMar Elias	Zahle	Beqaa	2,059.10	18.43
Brital	Baalbek	Baalbek-El Hermel	2,058.73	4,296.89
Ksara	Zahle	Beqaa	2,058.46	22.13
Deir El-Ghazal	Zahle	Beqaa	2,058.37	695.48
Aayha	Rachaya	Beqaa	2,058.33	4,295.74
Aarsal	Baalbek	Baalbek-El Hermel	2,058.21	31,689.70
Zahleh Er-Rassiyeh	Zahle	Beqaa	2,058.18	10.77
Qaa Baayoun	Baalbek	Baalbek-El Hermel	2,058.16	7,077.90
Aain Bourday	Baalbek	Baalbek-El Hermel	2,058.15	1,897.63
Mhaiydseh Rachaiya	Rachaya	Beqaa	2,058.13	1,424.00
Jenta	Baalbek	Baalbek-El Hermel	2,058.00	1,295.39
Ras Baalbek El Gharbi	El Hermel	Baalbek-El Hermel	2,057.58	5,411.17
Bednayel Baalbak	Baalbek	Baalbek-El Hermel	2,057.22	5,027.70
Qoussaya	Zahle	Beqaa	2,056.86	1,807.65
Saadnayel	Zahle	Beqaa	2,056.80	546.76
Zahleh El-Berbara	Zahle	Beqaa	2,056.72	21.41
Dahr El-Ahmar	Rachaya	Beqaa	2,056.29	998.02
Taanayel	Zahle	Beqaa	2,056.09	598.85
Dalhamiyet Zahleh	Zahle	Beqaa	2,055.87	523.47
Dar El-Ouassaa	Baalbek	Baalbek-El Hermel	2,055.60	583.42
Zahleh Haouch Ez-Zaraane	Zahle	Beqaa	2,055.44	24.82
Barr Elias	Zahle	Beqaa	2,055.31	2,418.30
Mdoukha	Rachaya	Beqaa	2,055.26	1,517.60
Biret Rachaiya	Rachaya	Beqaa	2,054.85	2,007.49
Chebrqiyet Tabet	Zahle	Beqaa	2,054.63	100.70
Majdel Aanjar	Zahle	Beqaa	2,053.86	2,532.32
Souairi	West Beqaa	Beqaa	2,053.50	1,409.76

Cadastral units	District	Mohafazat	Mean GHI (kWh/m^2)	Area (ha)
Slouqi	Baalbek	Baalbek-El Hermel	2,053.33	1,655.03
Kamed El-Laouz	West Beqaa	Beqaa	2,053.26	1,549.56
Barqa	Baalbek	Baalbek-El Hermel	2,053.22	1,952.26
Zahleh Aradi	Zahle	Beqaa	2,053.17	1,531.88
Khirbet Rouha	Rachaya	Beqaa	2,053.04	1,436.77
Kaoukaba Bou Arab	Rachaya	Beqaa	2,053.02	507.09
Marj BG	West Beqaa	Beqaa	2,052.74	876.25
Raouda (Istabel)	West Beqaa	Beqaa	2,052.68	569.97
Taalbaya	Zahle	Beqaa	2,052.52	503.88
Ouadi El-Aarayech	Zahle	Beqaa	2,052.24	655.09
Haouch Mandara	Zahle	Beqaa	2,051.59	398.89
Majdel Balhis	Rachaya	Beqaa	2,051.55	2,003.47
Joubb Jannine	West Beqaa	Beqaa	2,051.20	1,574.35
Harimeh Es-Soughra	West Beqaa	Beqaa	2,050.58	459.13
Aaqabet Rachaya	Rachaya	Beqaa	2,050.49	629.35
Terbol Zahleh	Zahle	Beqaa	2,049.49	1,671.26
Kfar Lichki	Rachaya	Beqaa	2,049.25	1,792.74
Nasriyet Zahleh	Zahle	Beqaa	2,049.05	171.30
Aain Aarab Rachaiya	Rachaya	Beqaa	2,048.95	1,105.15
Ghazzeh	West Beqaa	Beqaa	2,048.84	769.11
Haouch El-Harime	West Beqaa	Beqaa	2,047.86	574.82
Ouaqf BG	West Beqaa	Beqaa	2,047.21	271.09
Kfar Denis	Rachaya	Beqaa	2,047.13	701.90
Khiara	West Beqaa	Beqaa	2,046.87	916.14
Yahfoufa	Baalbek	Baalbek-El Hermel	2,046.70	1,227.09

Cadastral units	District	Mohafazat	Mean GHI (kWh/m^2)	Area (ha)
Jazira BG	West Beqaa	Beqaa	2,046.66	407.16
Mansoura BG	West Beqaa	Beqaa	2,046.53	780.60
Khiara El-Aatiqa	West Beqaa	Beqaa	2,046.42	235.84
Chtaura	Zahle	Beqaa	2,045.81	153.31
Baaloul BG	West Beqaa	Beqaa	2,045.75	1,250.90
Qaa Ouadi El-Khanzir	Baalbek	Baalbek-El Hermel	2,045.54	6,478.26
Manara (Hammara) BG	West Beqaa	Beqaa	2,045.48	1,412.41
Chebrqiyet Aammiq	West Beqaa	Beqaa	2,044.24	686.36
Makseh	Zahle	Beqaa	2,043.90	445.67
Tell El-Akhdar	Zahle	Beqaa	2,043.35	669.76
Dakoueh	West Beqaa	Beqaa	2,043.34	799.69
Tall Znoub	West Beqaa	Beqaa	2,043.27	779.38
Sohmor	West Beqaa	Beqaa	2,043.01	1,140.90
Soltan Yacoub el Aradi	West Beqaa	Beqaa	2,043.00	170.36
Aanjar (Haouch Moussa)	Zahle	Beqaa	2,042.06	1,621.56
Tcheflik Qiqano	Zahle	Beqaa	2,041.91	198.09
Nabha Ed-Damdoum	Baalbek	Baalbek-El Hermel	2,041.84	9,203.77
Mazraat beit Mchaik	Baalbek	Baalbek-El Hermel	2,040.41	1,297.53
Qabb Elias	Zahle	Beqaa	2,040.13	1,303.43
Jdita	Zahle	Beqaa	2,039.71	618.82
Lala	West Beqaa	Beqaa	2,038.97	1,373.84
Nabi Safa	Rachaya	Beqaa	2,038.27	813.13
Zebdoul	Zahle	Beqaa	2,037.96	93.14
Zighrine	El Hermel	Baalbek-El Hermel	2,037.89	9,372.57

Cadastral units	District	Mohafazat	Mean GHI (kWh/m²)	Area (ha)
Qaa Jouar Maqiy ├┌	Baalbek	Baalbek-El Hermel	2,037.35	2,466.22
Qaraaoun	West Beqaa	Beqaa	2,037.29	2,557.98
Soultan Yaacoub Faouqa	West Beqaa	Beqaa	2,036.68	1,164.82
Libbaya BG	West Beqaa	Beqaa	2,036.44	1,238.63
Haouch Es-Siyadeh	Zahle	Beqaa	2,034.35	140.13
Qaa Er-Rim	Zahle	Beqaa	2,034.17	2,996.10
Kfarzabad	Zahle	Beqaa	2,033.10	2,464.44
Touaite Zahleh	Zahle	Beqaa	2,032.99	1,633.91
Hermel	El Hermel	Baalbek-El Hermel	2,032.56	13,112.89
Aain Kfar Zabad	Zahle	Beqaa	2,032.19	497.44
Haouch Qayssar	Zahle	Beqaa	2,031.45	130.50
Aain El-Barnaya	Baalbek	Baalbek-El Hermel	2,031.41	1,760.63
Ham	Baalbek	Baalbek-El Hermel	2,031.22	1,540.18
Nahleh baalbek	Baalbek	Baalbek-El Hermel	2,030.20	12,338.35
Aammiq BG	West Beqaa	Beqaa	2,030.20	1,734.01
Beit Lahia	Rachaya	Beqaa	2,030.10	391.83
Aain Es-Siyaa Chadoura	Baalbek	Baalbek-El Hermel	2,029.69	2,448.41
Chaaibeh	Baalbek	Baalbek-El Hermel	2,029.27	1,753.87
Aamchki	Baalbek	Baalbek-El Hermel	2,028.64	5,545.88
Rachaiya	Rachaya	Beqaa	2,028.57	6,126.69
Aana	West Beqaa	Beqaa	2,027.39	1,493.61
Yammouneh	Baalbek	Baalbek-El Hermel	2,027.17	2,951.40
Deir Tahniche	West Beqaa	Beqaa	2,025.20	389.18
Tcheflik Edd ├┌ Haouch	Zahle	Beqaa	2,024.19	281.01
Hermel Jbab	El Hermel	Baalbek-El Hermel	2,023.87	7,498.19
Bakkifac Rachaya	Rachaya	Beqaa	2,023.39	837.22
Mrayjat Zahleh	Zahle	Beqaa	2,023.32	471.55

Cadastral units	District	Mohafazat	Mean GHI (kWh/m²)	Area (ha)
Hazerta	Zahle	Beqaa	2,021.96	666.28
Aaynata Bent Jbayl	Bent Jbeil	El Nabatieh	2,021.60	436.80
Maroun Er-Ras	Bent Jbeil	El Nabatieh	2,020.95	752.75
Kounine	Bent Jbeil	El Nabatieh	2,020.25	1,292.18
Mhaibib	Marjaayoun	El Nabatieh	2,019.16	475.13
Bent Jbayl	Bent Jbeil	El Nabatieh	2,017.59	800.98
Kafraiya BG	West Beqaa	Beqaa	2,017.07	1,744.53
Mzaraat Zahleh	Zahle	Beqaa	2,016.32	89.48
Maydoun	West Beqaa	Beqaa	2,016.15	1,052.10
Blida	Marjaayoun	El Nabatieh	2,016.06	1,328.87
Haouch El Qinnabeh Rachaiya	Rachaya	Beqaa	2,015.97	756.44
Aaintaroun	Bent Jbeil	El Nabatieh	2,015.64	1,360.66
Marj Ez-Zouhour (Haouch El-Qinnaabeh)	Hasbaya	El Nabatieh	2,015.16	649.20
Bouarej	Zahle	Beqaa	2,014.97	346.79
Deir Aain Ej-Jaouzeh	West Beqaa	Beqaa	2,014.91	308.18
Dellafeh	Hasbaya	El Nabatieh	2,013.52	379.92
Khirbet Qanafar	West Beqaa	Beqaa	2,012.24	2,142.65
Chaqra	Bent Jbeil	El Nabatieh	2,011.09	1,687.56
Meiss Ej-Jabal	Marjaayoun	El Nabatieh	2,011.04	1,922.32
Yaroun	Bent Jbeil	El Nabatieh	2,010.97	1,538.87
Baraachit	Bent Jbeil	El Nabatieh	2,008.53	630.25
Beit Yahoun	Bent Jbeil	El Nabatieh	2,008.51	485.12
Aaynata Baalbek	Baalbek	Baalbek-El Hermel	2,008.09	4,596.33
Saghbine	West Beqaa	Beqaa	2,007.64	1,464.67
Yohmor BG	West Beqaa	Beqaa	2,007.53	898.09
Tannoura	Rachaya	Beqaa	2,005.18	428.27
Mchaa El Ftouh	Kesrwane	Mount Lebanon	2,004.97	3,237.34

Cadastral units	District	Mohafazat	Mean GHI (kWh/m²)	Area (ha)
Aain Zebdeh	West Beqaa	Beqaa	2,004.47	523.12
Maaraboun	Baalbek	Baalbek-El Hermel	2,004.32	1,080.39
Houla	Marjaayoun	El Nabatieh	2,004.24	1,469.94
Aamra	Marjaayoun	El Nabatieh	2,004.11	1,273.01
Machghara	West Beqaa	Beqaa	2,003.76	2,429.22
Aain Ibl	Bent Jbeil	El Nabatieh	2,001.99	1,154.65
Ouadi Ed-Delm	Zahle	Beqaa	2,001.16	642.48
Qelaya	West Beqaa	Beqaa	2,001.11	557.09
Aain Et-Tineh BG	West Beqaa	Beqaa	2,001.03	675.48
Meimes	Hasbaya	El Nabatieh	2,000.18	1,533.97
	Total area (ha)			**416,229.87**

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