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# Thematic Report

# Night-time Light Reflectance:

## A New Economic Vulnerability Score (EVS) For Lebanon

October 2023



*Credit: Bryan Denton*

The Lebanon Crisis Analytics Team (LCAT) provides reactive and in-depth context analysis to inform the aid community in Lebanon. The information and analysis contained in this report is therefore strictly to inform humanitarian and development actors and associated policymaking on Lebanon.

*This study/report is made possible by the support of the American People through the United States Agency for International Development (USAID) and European Union Humanitarian Aid. The contents of this report are the sole responsibility of the LCAT and do not necessarily reflect the views of USAID, the United States Government, or the European Union.*

# Executive summary

This report builds on the Lebanese Crisis Analytics Team's (LCAT) first report in its nightlights series,[1] which highlighted the utility of using night-time light reflectance (NLR) data to monitor Lebanon's economy at multiple levels of geographic disaggregation. The previous paper proposed NLR as an alternative source of evidence to identify pockets of vulnerabilities at the local level, particularly when other sources contain data and information gaps. In Lebanon's challenging data landscape, where reliable quantitative data is difficult to obtain, LCAT seeks to bring to the aid community new methods of data collection and analysis to ensure that government-led and aid-focused interventions are appropriately targeted.

This working paper details the formulation of the economic vulnerability score (EVS), an indicator of economic activity comprising statistics derived from NLR data. NLR is a useful proxy for electricity consumption, and to a lesser extent availability.[2] Changes in NLR can therefore indicate households' ability or inability to maintain pre-crisis levels of electricity usage. While the EVS is not intended to replace traditional detailed needs assessments, it can be used when data is outdated and for locations with low data coverage. Testing of the EVS score showed that its results correspond with available data on food insecurity[3] and household poverty[4] at the qada level, as well as a UN list of Lebanon's 332 most vulnerable cadasters.[5]

Updated EVS data is available on the LCAT Data Analysis Hub via an interactive map or as a data download. The EVS has been used by Mercy Corps as a primary indicator for program targeting[6], and it is our hope that this paper will encourage further research and development of novel proxy indicators that can aid in humanitarian targeting and operations. Further research is required to elucidate geographical disparities in EDL energy provision and their intersection with decentralized alternatives, economic vulnerability, and social dynamics.

***Satellite imagery data sources:***
*NLR images were taken by the VIIRS satellite and are freely available on The Earth Observation Group website. Mercy Corps does not capture satellite images or engage in surveillance activities.*

[1] Lebanese Crisis Analytics Team, Night-time Light Reflectance: Potential Uses in Lebanon, September 4, 2023.
[2] "Electricity consumption" in the paper refers to the additional electricity consumed to compensate for lower levels of electricity available from Electricité du Liban (EDL). Changes in NLR could theoretically also indicate changes in the availability of state-provided electricity. However, since there is little to no geographically disaggregated data on changes in EDL coverage, the paper assumes that EDL provision has diminished at an equal rate across the country, and therefore NLR remains reflective of economic vulnerability.
[3] Percent of households with an Integrated Food Security Phase Classification score of 3 or more.
[4] The Household Deprivation Score (HDS) and Multidimensional Poverty Index (MPI).
[5] UN Inter-Agency Coordination map.
[6] Specifically, as an indicator to inform the program's decision on which cadaster to target in a selected qada. This targeting is done in conjunction with other factors, such as accessibility, the presence of other humanitarian aid actors and stakeholder engagement.


Credit: Roudy Doumit

# Introduction

## Measuring Economic Vulnerability Using Night Lights Reflectance

Vulnerabilities in Lebanon are difficult to identify due to a lack of reliable and regularly updated quantitative data, particularly at the local level. To propose a method by which this deficiency can be addressed, LCAT published a report in early September 2023 titled "Night-time Light Reflectance: Potential Uses in Lebanon",[7] which highlighted the relationship between night-time lights reflectance (NLR) dynamics and electricity consumption in Lebanon. Since electricity consumption is related to diesel prices relative to household income, NLR data should be useful in identifying economically vulnerable areas in Lebanon. The current humanitarian data landscape in Lebanon lacks up-to-date and publicly available vulnerability data at the cadaster level. Fortunately, NLR data is refreshed regularly and can be aggregated into cadaster boundaries,[8] which presents an opportunity to fill this information gap with constantly updated data[9] to precisely identify the most economically vulnerable areas of Lebanon.

[7] A Lebanese Crisis Analytics Team, Night-time Light Reflectance: Potential Uses in Lebanon, September 4, 2023.
[8] All cadasters classified as disputed ("Litige") by UNOCHA were removed from the analysis.
[9] Monthly composite VIIRS satellite images are published about three months after they were originally captured.


Credit: Diego Ibarra

# Key Findings

- LCAT produced the economic vulnerability score (EVS) indicator to identify pockets of vulnerability at the local level using data on changes in NLR concentration and fuel prices, which accounts for a relative lack of available data across most of Lebanon.
- The EVS corresponds well to existing common vulnerability indicators, specifically, the Integrated Food Security Phase Classification, Household Deprivation Score, and Multidimensional Poverty Index.
- Statistical correspondence between the EVS and UNHCR list of most vulnerable cadasters suggests that the EVS can also be used to accurately identify economically vulnerable cadasters.
- Economically vulnerable cadasters are found throughout the country and most concentrated in the qadas of Tripoli, Zahle, Beirut, and Akkar.
- The EVS can be replicated for other contexts, specifically those with decentralized electricity production, with northern Yemen and Nigeria being possible future use cases.

# Methodology

## Calculating the EVS

LCAT developed the EVS using the following two statistics calculated wholly or in part from NLR data:

**1. Price elasticity of generator costs**: The correlation[10] between diesel prices and NLR per-geographic unit.

- **A negative correlation** indicates that a community was less able to maintain electricity consumption when generator costs increased due to higher diesel prices. This is the case in Mar Moussa (Metn) (Figure A1) where NLR has shrunk progressively as the cost of diesel increased, yielding a strong negative correlation (r=-0.59). Therefore, stronger inverse correlations indicate high price elasticity, which can be linked to relatively higher levels of economic vulnerability.
- **A positive correlation** indicates that a community was more able to maintain electricity consumption when generator costs increased. Batroun (Figure A1) is a good example of this type of community, demonstrating relatively stable NLR levels in the face of increasing diesel costs. This relative price inelasticity can be linked to lower levels of economic vulnerability.[11]

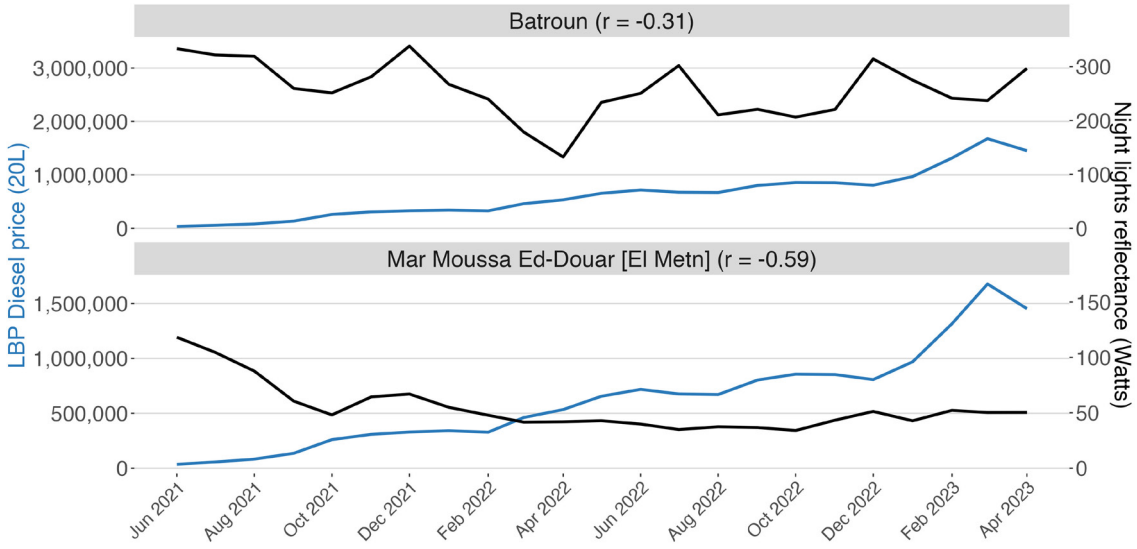



***Figure 1**: Figure 1. The price of diesel against NLR levels in the cadasters of Batroun and Mar Moussa Ed-Douar (Metn). The correlation coefficient (Pearson's r) in the graph was calculated using the growth rate of diesel prices and NLR values. The blue line shows the LBP-denominated price of 20 liters of diesel fuel, which corresponds to the left-side y-axis. The black line shows the change in night lights reflectance in the named location, which corresponds with the right-side y-axis.*

[10] Correlation coefficients are calculated using diesel and NLR growth rates from July 2021 (after fuel subsidies were removed) to the latest monthly NLR image; in this case, April 2023.

[11] Weak or positive correlations may also be found in areas with centralized electricity provision, such as locations where hydroelectricity is the primary source of electricity; therefore, analysts must ensure the EVS is only used in areas where electricity provision is primarily decentralized, or just as a comparison among locations where electricity provision is more centralized.

**2. Change in NLR concentration:** The change in NLR concentration[12] [13], per-geographic unit. The rate of change is calculated between the latest monthly NLR satellite image and that same month in 2019.

- **More concentrated NLR values**[14] indicate that levels of electricity consumption in the geographic unit changed from a traditional frequency distribution of values (few low NLR pixels, many medium NLR pixels, and few high NLR pixels) to a relatively uniform frequency distribution, which indicates that most households in the area reduced their electricity consumption to a minimum viable level.
- For example, in Figure A2, the coefficient of variation (CoV) for Qoussaya cadaster (Zahle district) greatly decreased during the crisis, meaning that NLR values became less dispersed and most areas within the cadaster diminished to similar low NLR levels.

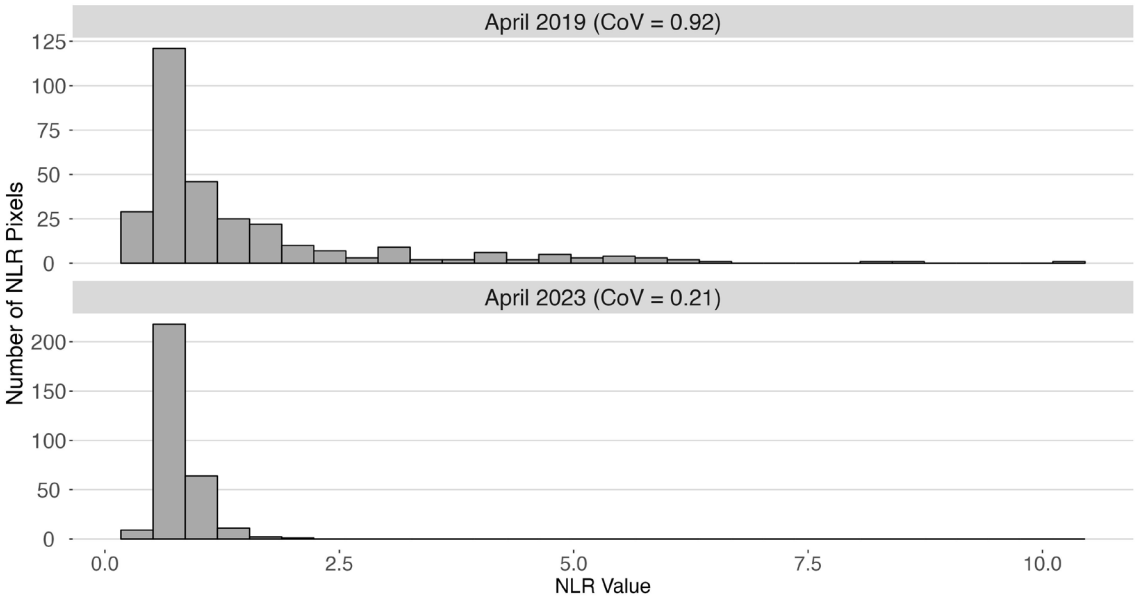



***Figure 2**: Histogram of the coefficient of variation (CoV) of NLR in Qoussaya cadaster (Zahle district).*

The EVS is the sum of the percentile ranking of these two indicators, classified among all cadasters in Lebanon. Lower scores represent higher economic vulnerability because negative values – and therefore lower percentile rankings – of the two input indicators indicate higher economic vulnerability. Cadasters with an EVS in the bottom quartile (25%) of all locations are categorized as highly vulnerable locations. Locations categorized as highly vulnerable (in the top quartile) are divided into thirds and labeled "Level 1", "Level 2", and "Level 3". Cadasters in the Level 3 category are the most economically vulnerable communities in Lebanon.

Population weights were also added to account for the operational balance between providing humanitarian assistance to the most vulnerable locations and also considering areas with a sizable population.

[12] NLR concentration is calculated using the coefficient of variation of NLR in a geographic unit. The coefficient of variation is a measure of dispersion calculated by dividing the standard deviation by the mean. A higher coefficient indicates higher dispersion, while a lower coefficient indicates lower dispersion.
[13] In cadasters covered by less than 30 NLR pixels, NLR growth rates were used in place of the coefficient of variation.
[14] Indicated by a reduction (negative growth rate) in the coefficient of variation.

The population-weighted score is the inverse of the unweighted EVS, multiplied by the population.[15] [16] [17] The inverse is used so that lower scores carry more weight than higher scores. For example, consider two casters: Cadaster A with an EVS of 13 (and inverse = 0.077) and Cadaster B with an EVS of 71 (and inverse = 0.014). Even if the population of Cadaster B is double that of Cadaster A (e.g., 5,000 people in Cadaster B and 2,500 people in Cadaster A), the overall population-weighted EVS indicates that Cadaster A is more vulnerable than Cadaster B because Cadaster B was less economically vulnerable because it had a noticeably higher unweighted EVS.

*Unweighted EVS (lower value = more vulnerable)*

$$\frac{Correlation\ between\ NLR\ and\ diesel\ growth\ rates}{1st\ percentile\ (1\ point)} + \frac{Increase\ in\ the\ concentration\ of\ NLR\ values}{81st\ percentile\ (81\ points)} = 82\ points$$

*Population-weighted EVS (higher value = more vulnerable)*

$$\left(\frac{1}{82}\right) \times\ 101,046\ (population)\ =\ 1232.5\ points$$

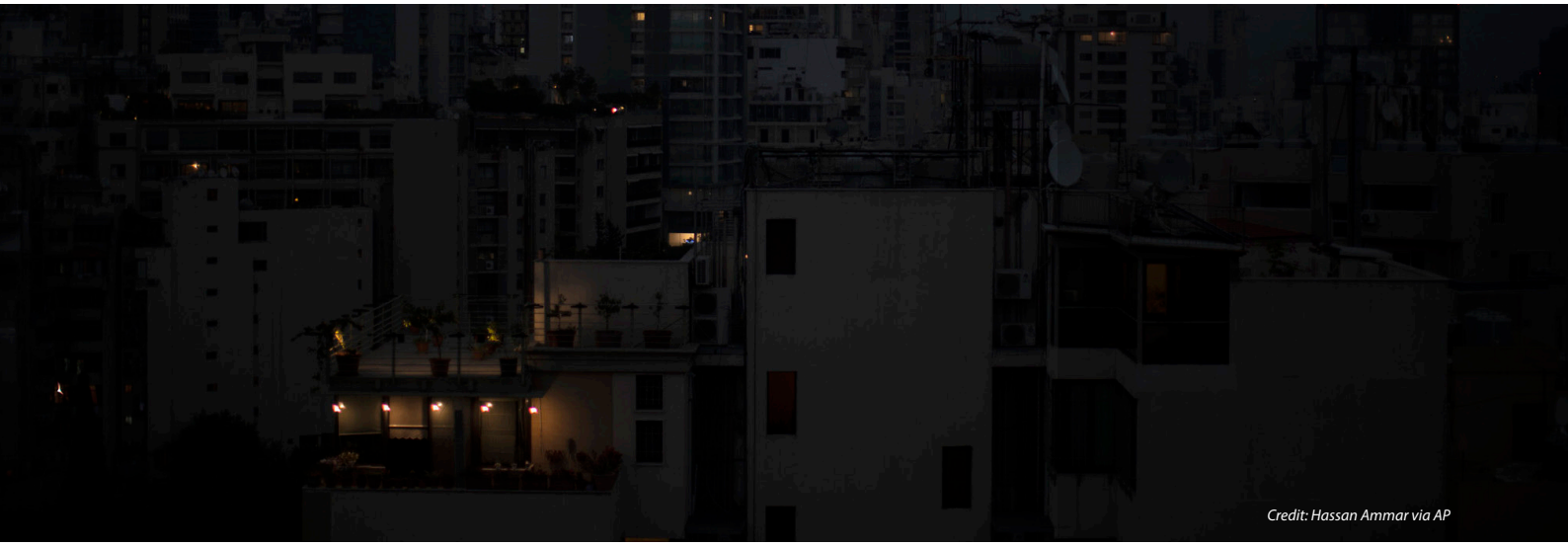
***Figure 3**: EVS calculations for Trablous Jardins (Tripoli)*

## Methodological Limitations

Electricity production in Lebanon is not completely decentralized; rather, decentralized generation from diesel generators and private solar is used as a backup energy source to fill in for gaps in EDL coverage. Therefore, NLR data is not a perfect proxy for electricity consumption, since NLR fluctuations may also reflect fluctuations in state provision. Unfortunately, there is no publicly available data on the hours of electricity provided by Electricité du Liban (EDL) and its variations across Lebanon; therefore, the EVS methodology assumes that the hours of electricity provided by EDL is uniformly geographically distributed across the country. Further, hydroelectric power is provided to some areas in Lebanon, as discussed in LCAT's previous NLR-focused paper[18] and noted in the geographic analysis of the EVS found in the following section of this paper. As a result, the EVS should be used with caution when measuring the economic vulnerability of areas where hydroelectric power is a primary source of electricity, or where EDL coverage may not have changed at the same rate as the national average.

In sum, LCAT acknowledges that neutral or positive correlations between diesel price and NLR dynamics may indicate either: 1.) A location's ability to maintain previous levels of electricity consumption by purchasing enough diesel to produce a sufficient amount of electricity using generators, or 2.) The availability of electricity through the grid (through hydroelectric dams or power plants).[19] Further research is required to show the geographical disparities in EDL energy provision and link this data to the availability and structure of decentralized alternatives and how this impacts on economic vulnerability and other social dynamics.

[15] Population data in Lebanon obtained from Kontur.
[16] Population estimates were calculated by multiplying the proportion of the Kontur hexagon inside a cadaster by the population of the cadaster, and then summing the population number of each partial (or whole) hexagon that falls inside each cadaster.
[17] Weighted EVS are interpreted differently; higher scores indicate higher economic vulnerability.
[18] Lebanese Crisis Analytics Team, Night-time Light Reflectance: Potential Uses in Lebanon September 4, 2023.
[19] Weak or positive correlations could also be attributed to relatively higher local levels of state power, but (again) this analysis assumes that electricity provided by EDL diminished at the same degree across the country.


Credit: Hassan Ammar via AP

# Testing the EVS

## Testing the EVS at the qada level

Statistical testing of the unweighted EVS with existing vulnerability indicators generated by other humanitarian agencies at the qada level provides evidence that the **EVS can be used as a reliable proxy measure for qada-level poverty and food insecurity.**

Successful triangulation of the qada-level EVS with similar indicators from other humanitarian agencies would support the utility of the EVS at the qada level. LCAT calculated the unweighted and population-weighted EVS of Lebanon's qadas and compared them to four other indicators of economic vulnerability:

1. The Household Deprivation Score[20]
2. The incidence of multidimensional deprivation[21]
3. The intensity of multidimensional deprivation[22]
4. The proportion of the Lebanese population classified with an IPC Phase 4 (Emergency)[23] [24], food insecurity score

The unweighted EVS produced a statistically significant relationship with similar indicators, but the population-weighted EVS did not. Therefore, the population-weighted statistical analysis results are not reported and population-weighted EVS cannot be recommended for identifying economically vulnerable districts in Lebanon. Group comparisons using t-test results shown in Figure 5 indicate that qadas considered vulnerable according to the EVS have statistically significantly higher multidimensional poverty index (MPI) incidence rates and a larger proportion of the population with a high Household Deprivation Score (HDS).[25] [26]

[20] WFP Lebanon, Food Security and Vulnerability Analysis of Lebanese Residents July 2022.
[21] Based on the multidimensional poverty index (MPI). Central Administration of Statistics & The World Bank, Lebanon Multidimensional Poverty Index 2019.
[22] Incidence refers to the proportion of the population in multidimensional poverty, and intensity indicates the average deprivation score experienced by low income individuals. See MPI 2022 FAQS.
[23] World Food Programme, IPC Acute Food Insecurity Analysis. September 2022 - April 2023.
[24] World Food Programme, IPC Acute Food Insecurity Analysis. Lebanon's food insecurity persists as economic crisis continues (May - October 2023).
[25] To ensure contemporary comparisons, the EVS calculated between January 2019 and January 2021 was compared to MPI indicators and the HDS.
[26] World Food Programme, The HDS is an index that ranks families on the basis of the number of deprivations they face across five minimum living standards: i) food, ii) health, iii) education, iv) shelter, and v)livelihoods. September 23, 2022.

Qadas categorized as economically vulnerable have a statistically significantly higher proportion of the population classified as IPC-3 food insecure in 2022 and 2023.[27] These statistical relationships support the EVS as a qada-level indicator of economic vulnerability that is most closely related to the proportion of the population that is impoverished and food insecure.

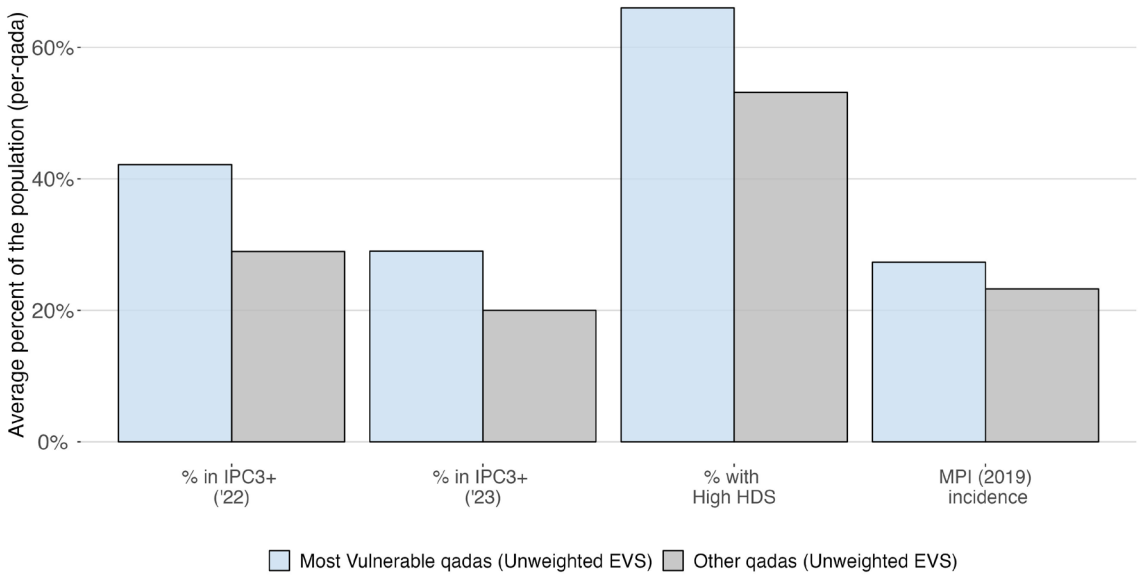



***Figure 4**: The average proportion of the population that was classified as economically vulnerable (unweighted EVS) by other indicators in qadas defined as economically vulnerable (or not) according to the unweighted EVS. All differences are statistically significant (p <= 0.05). Household Deprivation Scores are considered "high" when the HDS >= 0.33.*

## Testing the EVS against UNHCR cadaster data

LCAT also tested the EVS against the UNHCR's ranked list of cadasters that host the highest number of displaced Syrians, Palestinian refugees, and vulnerable Lebanese. This UNHCR list, which is largely based on WFP's mVAM 2022, is the only recent (2022) publicly-available cadaster-level vulnerability dataset.[29]

The cadaster-level population-weighted EVS corresponds well to UNHCR's list of Lebanon's 332 most vulnerable cadasters, which suggests the indicator is useful for identifying vulnerable cadasters and, more broadly, is additional evidence that the EVS functions well as a proxy for economic vulnerability.[30] About 73% of the cadasters identified as vulnerable using the population-weighted EVS were identified as vulnerable by UNHCR.[31]

[27] To ensure contemporary comparisons, 2022 IPC data was compared to the unweighted EVS calculated between December 2019 and December 2022, and 2023 IPC data was compared to the unweighted EVS calculated between April 2019 and April 2023.
[28] UNHCR, Lebanon: Inter-Agency Coordination - The 332 localities in Lebanon that host the highest number of displaced Syrians, Palestinian refugees, and deprived Lebanese October 28, 2022.
[29] To ensure a contemporary comparison, the EVS calculated between December 2019 and December 2022 was compared to the UNHCR categorization.
[30] These similarities also should spur further research on the determinants and dynamics of economic vulnerability in Lebanon, such as the effects of internal migration, social cohesion, and remittance inflows.
[31] This finding was reached using a t-test and a Mann-Whitney test comparing the population-weighted EVS in cadasters classified and not classified as vulnerable by UNHCR ($t = -5.20$, $p < 0.000$; $W = 39{,}401$, $p < 0.000$). The population-weighted EVS in cadasters categorized by UNHCR as vulnerable were on average about 10 times higher (more vulnerable) than cadasters not classified by UNHCR.

Conversely, though cadasters identified by UNHCR as vulnerable were statistically more vulnerable according to the unweighted EVS,[32] only approximately 30% of cadasters identified as vulnerable by the unweighted EVS were listed as vulnerable by UNHCR.

The average EVS per-UNHCR vulnerability category is shown in Figure 1, and illustrates a strong correspondence between the population-weighted EVS and UNHCR vulnerability ranking. Discrepancies between cadasters identified as vulnerable using the population-weighted EVS and UNHCR vulnerability ranking may be attributed to UNHCR's weighting of non-Lebanese population groups (Syrian and Palestinian refugees) and potential confounding factors related to NLR data, such as the electricity provision from hydroelectric power sources and the prevalence of solar power installations.

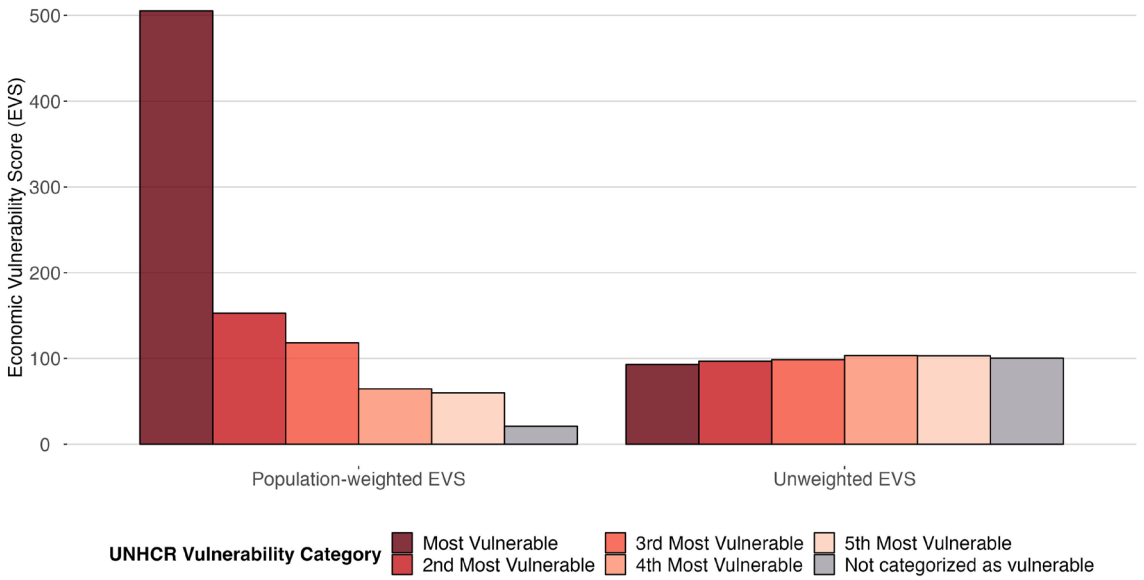
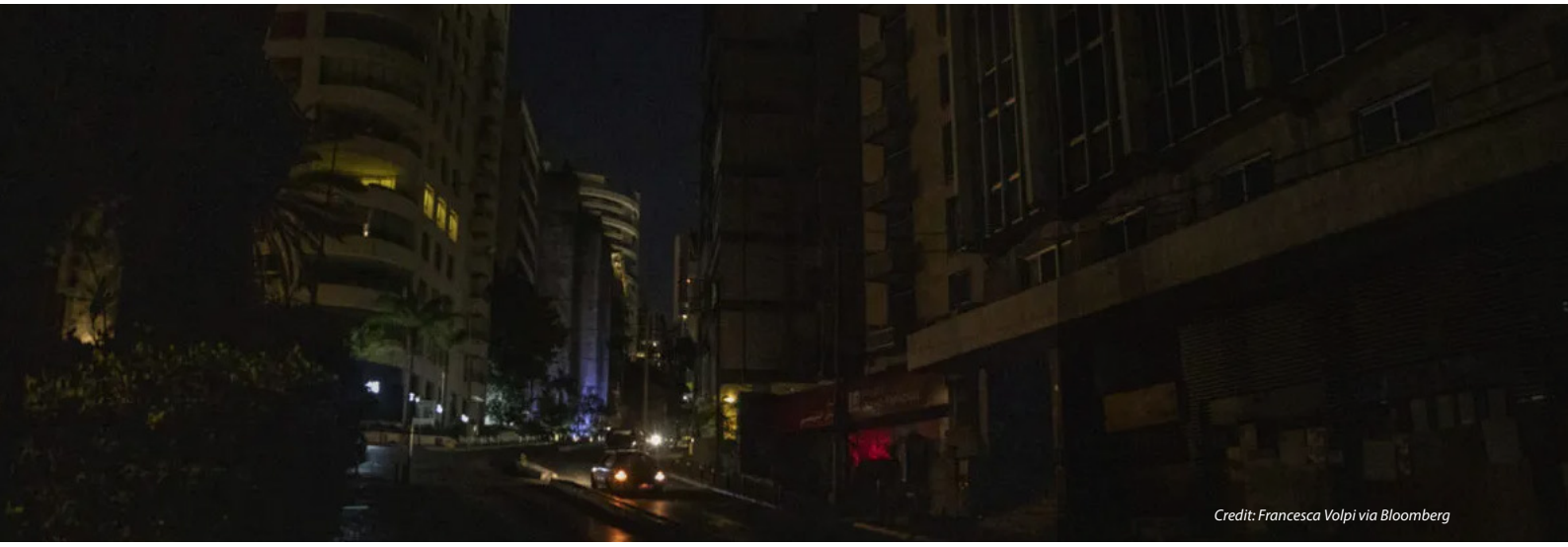



***Figure 5**: The average unweighted and population-weighted EVS of each UNHCR vulnerability category. Lower unweighted EVS and higher population-weighted EVS indicate greater economic vulnerability.*

[32] This finding was reached using a t-test and a Mann-Whitney test comparing the unweighted EVS in cadasters classified and not classified as vulnerable by UNHCR ($t = 2.24$ $p < 0.03$; $W = 216{,}088$, $p < 0.04$). The unweighted EVS in cadasters categorized by UNHCR as vulnerable were on average about 5% lower (more vulnerable) than cadasters not classified by UNHCR.


Credit: Francesca Volpi via Bloomberg

# Geographic distribution analysis of the cadaster level EVS

The successful robustness tests of the population-weighted (and to a lesser extent, unweighted) EVS at the cadaster level enabled the analysis of geographic distribution scores, which are shown in Figure 6 and 7. According to the latest EVS (April 2019 to 2023), about 82% of cadasters in Tripoli qada were classified as highly economically vulnerable using the unweighted EVS, followed by Beirut (54%), Zahle (51%), and Akaar (44%). Tripoli qada had the highest proportion of cadasters with a Level 3 unweighted EVS categorization (65%), followed by Beirut (39%), Zahle (26%), Batroun (26%), and Akkar (16%). Figure 8 (left panel) shows concentrations of (unweighted) EVS, with clusters[33] of less vulnerable cadasters visible in the qadas of Jezzine, Eastern Chouf, and West Bekaa,[34] as well as in the western halves of Metn and Keserwane.

Clusters of population-weighted EVS were located in major urban centers and eastern Baalbek qada. All the cadasters in Beirut and Tripoli qadas, and 56% of cadasters in Zahle qada were categorized as economically vulnerable.

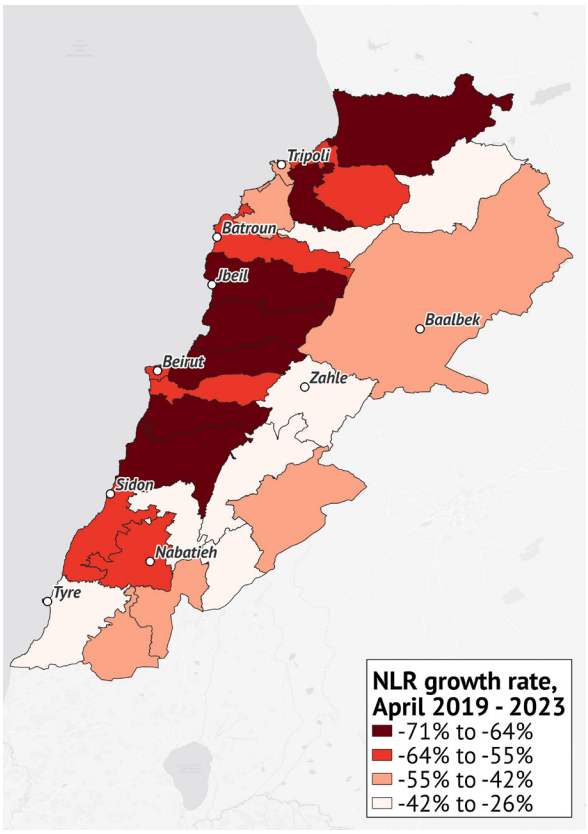



***Figure 6**: The most economically vulnerable cadasters in Lebanon, according to the unweighted EVS. The calculation uses the latest EVS (April 2019 to 2023). Level 3 is the highest economic vulnerability level. Unmarked cadasters fall outside of the top 25% most vulnerable cadasters.*

[33] According to Local Moran's I statistics; Global Moran's I score = 0.44 (p = 0.001).
[34] This is likely due to the prevalence of hydroelectric power in the area, which reduces reliance on generators. This will be investigated when comparing the EVS to upcoming cadaster-level vulnerability data in Lebanon, and accounted for in an updated EVS calculations, if necessary.

Furthermore, Nabatieh (54%) and Baabda (49%) had the next highest proportions of economically vulnerable cadasters. Beirut (92%) had the highest proportion of cadasters in the Level 3 category, followed by Tripoli (77%), Baabda (28%), Nabatieh (19%), and Metn (19%). Figure 8 (right panel) shows concentrations of (population-weighted) vulnerability, with clusters[35] of less vulnerable cadasters (higher unweighted EVS) apparent in most of Jbeil (east of the coastal cadasters), north-central Akkar,[36] and western Jezzine.[37]

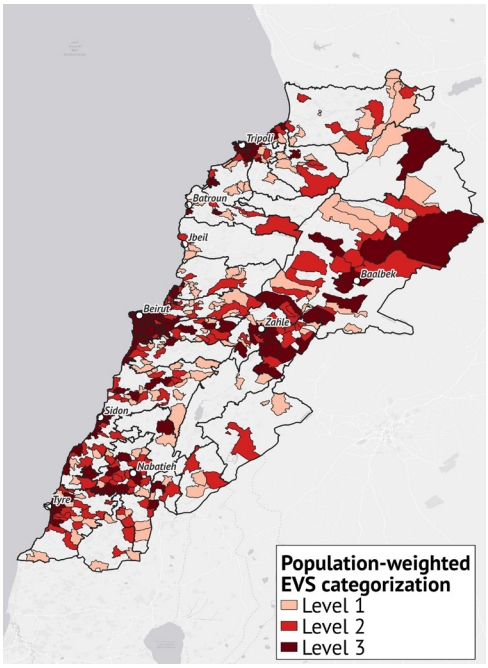



***Figure 7**: The most economically vulnerable cadasters in Lebanon, according to the population-weighted EVS. The calculation uses the latest EVS (April 2019 to 2023). Level 3 is the highest economic vulnerability level. Unmarked cadasters fall outside of the top 25% most vulnerable cadasters.*

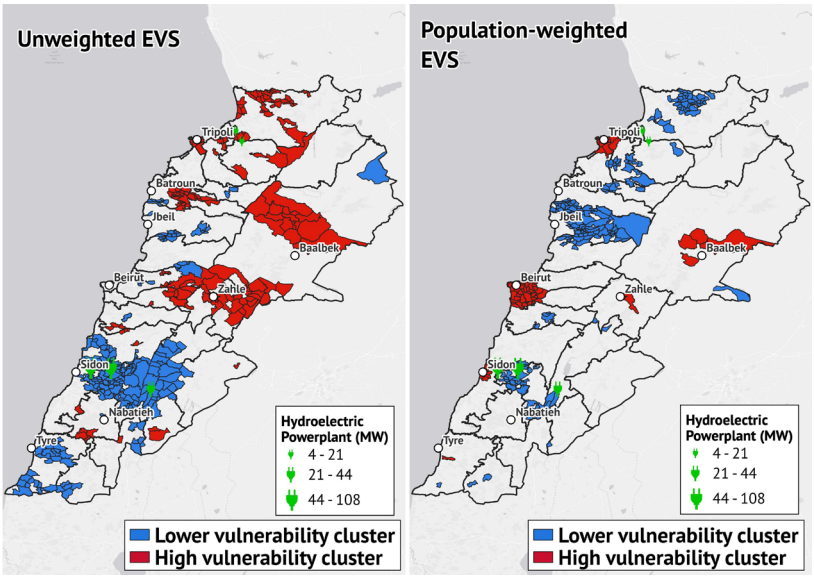



***Figure 8**: Clusters[38] of higher and lower economic vulnerability in Lebanon, using the latest monthly EVS (April 2019 to 2023).*

[35] According to Local Moran's I statistics; Global Moran's I score = 0.57 (p = 0.001).
[36] The designation of north-central Akkar as less vulnerable is primarily due to very low population numbers.
[37] The designation of Jezzine as less vulnerable is likely due to the prevalence of hydroelectric power in the area, as labeled on the map. Cadasters that primarily receive their electricity from hydroelectric dams should be considered outliers and excluded from vulnerability analyses using the EVS.
[38] Taken from the local indicator of spatial association (LISA) statistic, which is an indication of the extent of significant spatial clustering of similar values around each observation (cadaster).

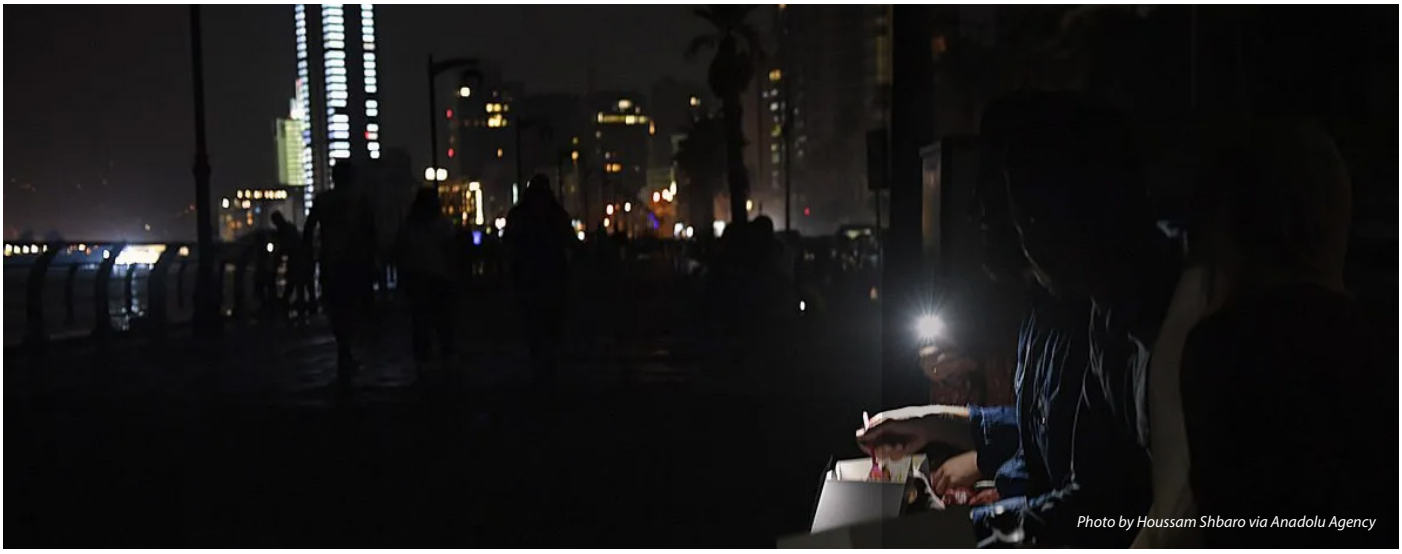


Photo by Houssam Shbaro via Anadolu Agency

# Conclusion

NLR data is particularly useful for analyzing economic activity in Lebanon due to the country's heavy reliance on private generators for electricity consumption since, by extension, changes in NLR are indicative of purchasing power.[39] This observation, in addition to the detailed analysis conducted in the LCAT report "Night-time Light Reflectance: Potential Uses in Lebanon", led to the development of an economic vulnerability score (EVS) calculated using two indicators derived from NLR statistics for Lebanon's districts and cadasters.

Robustness checks indicate that the population-weighted EVS is comparable to the recent UNHCR cadaster vulnerability ranking, and the unweighted EVS is comparable to other indicators of economic vulnerability at the district level. Therefore, the population-weighted EVS is recommended for identifying and prioritizing economically vulnerable cadasters, and the unweighted EVS is recommended for identifying economically vulnerable districts in Lebanon.[40] Moreover, the EVS uses frequently updated and freely-available data, which is particularly useful when national vulnerability assessments are geographically constrained, outdated, or not financially feasible. This paper has highlighted the limitations of the EVS, specifically issues arising from the fact that electricity production is not completely decentralized in Lebanon, and so NLR cannot be a perfect proxy for economic vulnerability without better data on EDL provision. Moreover, the EVS only works in contexts where electricity generation is heavily decentralized, with localized power generation representing consumers' main source of electricity. This means that the EVS methodology would be best replicated in other humanitarian contexts where electricity provision is heavily decentralized, such as areas of Yemen under the control of the de-facto authority and northeast Nigeria. LCAT hopes that this paper will spark discussion about both the benefits of the EVS to humanitarian actors in Lebanon and its potential applicability in other humanitarian contexts.

[39] This suggests its applicability in other humanitarian contexts where electricity provision is largely decentralized, such as DfA-controlled Yemen and northern Nigeria.
[40] The latest economic vulnerability scores available upon request from LCAT and visualized on the LCAT Data Analysis Hub.

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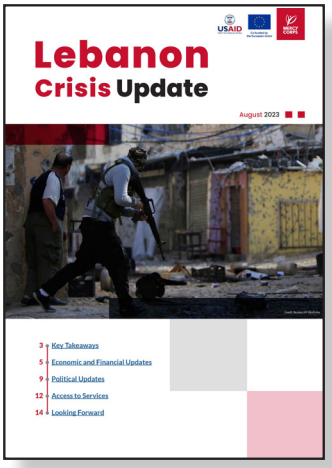



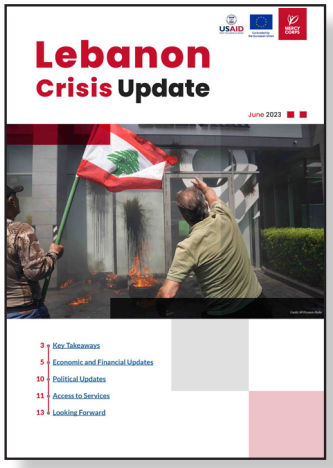


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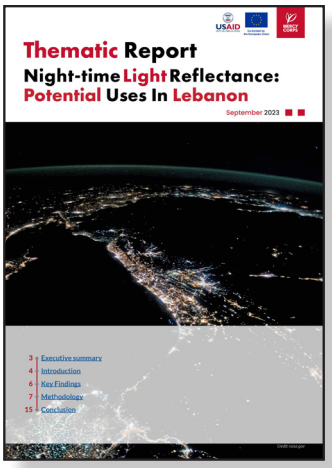




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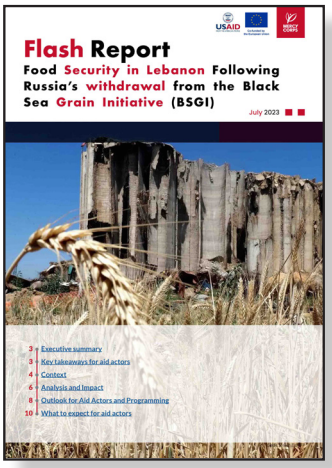



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Mercy Corps is a leading global organization powered by the belief that a better world is possible. In disaster, in hardship, in more than 40 countries around the world, we partner to put bold solutions into action — helping people triumph over adversity and build stronger communities from within. Now, and for the future.