



# USING NIGHT LIGHTS TO MEASURE ECONOMIC OUTPUT IN SYRIA

**QUANTITATIVE REPORT**

27 May 2021



# EXECUTIVE SUMMARY

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Regional estimates of gross domestic product (GDP) do not exist for Syria, but night light reflectance data (NLRD) collected in sets of satellite imagery is useful for disaggregating estimates of national economic output. Using two common satellites that capture night light reflectance, we calculate inflation-adjusted (real) GDP for all Syrian subdistricts from 2000 to 2020, which covers the pre-war and conflict economy. Our methodology was adopted from similar past research and uses NLRD to disaggregate and improve national GDP estimates.

The results highlight the urbanization of the Syrian economy before the war, and the economic devastation inflicted by the ongoing conflict, particularly in the northwest and areas formerly occupied by ISIS. NLRD is also useful for assessing urban development and electricity provision, and is a modest indicator of the spatial concentration of building damage. HAT will share the subdistrict-level real GDP estimates produced in this report upon request, which can be easily aggregated into higher geographies (for example at governorate level), to assist humanitarian and development actors plan livelihood, resilience, and redevelopment programming.

This paper presents the second quantitative measurement developed by the Syria HAT team in 2021, as HAT continues to grow and develop the humanitarian data landscape. These quantitative measurements aim to fill existing data gaps and to develop unified methodologies that can be applied across all areas of control.

# KEY POINTS

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- › Statistics on regional economic output, typically measured as GDP, do not exist for Syria.
- › Night lights reflectance data from satellite imagery is useful for disaggregating GDP estimates to subnational geographies with reasonable accuracy.
- › Night light reflectance data improves the accuracy of official GDP estimates by correcting for measurement errors unrelated to those produced by official estimation methods.
- › Deir-ez-Zor was the only governorate to experience economic decline during the 2000s, with most growth occurring around urban centers (ie, Damascus, Homs, and Aleppo) and in coastal governorates.
- › The economies of Al-Hasakeh and Dar'a governorates have experienced the greatest recovery to 2012 real GDP levels.
- › Subdistricts in and around Idleb city and those formerly occupied by ISIS experienced the greatest amount of economic decline; the most notable example of Idleb itself, whose GDP declined by 94% during the conflict.
- › Economic growth is centered in areas along international borders, and those close to different zones of control; these include Ya'robiyah (Syria-Iraq border), Harim (Syria-Turkey border), and Rabee'a (Syria-Lebanon border).
- › Night lights reflectance is useful for assessing urban development and electricity provision, and is modestly associated with the spatial concentration of building damage.

HAT will publicly share the subdistrict-level real GDP estimates produced in this research to assist humanitarian and development actors plan livelihood, resilience, and redevelopment programming.

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# CONTENTS

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Executive summary	2
Key points	3
Contents	4
Introduction	5
The Syrian economic context	6
Syria’s conflict-economy	8
Part I. Night lights reflectance data	10
Night light reflectance satellite imagery	10
Night light reflectance and economic activity	12
Part II. Estimating regional GDP	14
Data	14
Spatial disaggregation	15
Night light corrected regional GDP	17
Part III. Analysis	20
GDP by Zone of Control	20
Governorates	21
Subdistricts	22
Cities	27
Conclusion	30
Appendix	32

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# INTRODUCTION

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The financial losses caused by the Syrian conflict are currently estimated at (US) \$324.5 billion.<sup>1</sup> However, while there are country level estimates of the economic costs of conflict, subnational economic estimates are almost non-existent, while those that do exist have questions over their accuracy. In order to fill this gap, and to build on the data landscape for Syria, Syria HAT has developed a proxy indicator for economic activity using night lights reflectance data (NLRD) collected by satellites which provide a consistent measurement of economic activity that can be applied across all zones of control and over time. This paper uses night light reflectance data to disaggregate and correct GDP estimates for Syria and analyze levels of subnational economic activity. Reliable subnational GDP estimates allows for further economic analysis measuring the drivers of growth, which will become more essential as more effort and resources are dedicated to rebuilding Syria.

The disaggregated regional GDP estimates calculated in this report are used to identify economic patterns within zones of control, governorates, and at the subdistrict level. Given their strong positive relationship to economic output, night light reflectance values are also useful for detailed spatial

analysis at the city level, where changes in urban development can be monitored. Further, the data is also useful for rapid damage assessments or electricity availability assessments because contemporary nightlights data is released daily and monthly with only a short delay.

The analytical results highlight and confirm regional economic trends that emerged in the 2000s, as well as those since the onset of conflict in 2011. Specifically, the results show that economic growth in Syria was centered on urbanization in the 2000s and shifted to areas that produce energy and remained relatively free of conflict, particularly Al-Hasakeh. The results also show what areas have been the slowest to recover, specifically, northwest Syria and the eastern desert, due to ongoing political violence and occupation by ISIS.

These estimates of regional real GDP provide otherwise unavailable information on where and to what extent economic damage and recovery have occurred, which we intend to share publicly to assist humanitarian and development efforts in efficiently and equitably rebuilding the Syrian economy.

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<sup>1</sup> Institute for Economics & Peace. [Economic Value of Peace 2021: Measuring the global economic impact of violence and conflict](#). Sydney, January 2021.

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## THE SYRIAN ECONOMIC CONTEXT

Former president Hafiz al-Assad (father of current president Bashar al-Assad) initiated the process of liberalizing Syria's centrally-planned economy in the five-year plan before his death in 2000. This was then reinforced by the Social Market Economy Strategy set out by Bashar and the Ba'athist party in 2005.<sup>2</sup> The plan reduced tariffs and the highest-tier income tax rates, and allowed private companies to enter the market and compete with state holdings, an alternative to the common market liberalization approach of privatizing state holdings.<sup>3</sup> However, the Syrian state continued to play a significant direct role in the economy by employing a large number of people and subsidizing select essential items, such as bread and fuel. The economic liberalization process also included international trade partnerships, with a request to join the World Trade Organization in 2004, and a free trade agreement with Turkey in 2007. In the decade before the conflict, Syria was classified as a lower-middle income country

with a strong average annual growth rate of 4% (2000–2010).<sup>4</sup> Surprisingly (due to the significance of oil in national economies), economic growth was driven by non-oil sector production, as oil-related real GDP growth declined by an average of 4.2% per-year from 2000 to 2010,<sup>5</sup> and non-oil real GDP growth expanded by an average of 6.6% per-year during the same period.<sup>6</sup> The country also had a balanced current account with international reserves able to cover more than nine months of imports.<sup>7</sup> Despite this, Syria's GDP per-capita (\$2,700<sup>8</sup> in 2010) remained considerably lower than its neighbors, Lebanon (\$15,000<sup>9</sup> in 2010) and Jordan (\$9,500<sup>10</sup> in 2010) throughout the decade.

Foreign investment contributed an average of 1.3% to GDP during the 2000s, mainly in pharmaceuticals, food processing, and textiles. Domestic investment was concentrated in trade, housing, banking, construction and tourism, with only 13% of foreign and domestic investment in

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<sup>2</sup> Abboud, S., [From the Social Market Economy to the National Partnership: The conflict elite and public-private partnerships in a post-war Syria](#), January 2019.

<sup>3</sup> World Bank. [The toll of war: The economic and social consequences of the conflict in Syria](#), 2017.

<sup>4</sup> Average real GDP growth rate, using data from: [FRED, GDP in constant prices for Syrian Arab Republic](#)

<sup>5</sup> Average oil real GDP growth rate, using data from: [FRED, Oil real GDP Growth in Constant Prices](#)

<sup>6</sup> Average non-oil real GDP growth rate, using data from: [FRED, Non-Oil Real GDP Growth in Constant Prices](#)

<sup>7</sup> World Bank. [The toll of war: The economic and social consequences of the conflict in Syria](#), 2017.

<sup>8</sup> Calculated by dividing real GDP ([FRED, Gross Domestic Product in Current prices](#)) by population statistics ([FRED, Population for Syria](#))

<sup>9</sup> World Bank Databank

<sup>10</sup> World Bank Databank

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manufacturing.<sup>11</sup> The Syrian government attempted to facilitate large private industrial projects and attract investors by establishing industrial zones in the late 1990s,<sup>12</sup> the largest zones developed in Aleppo (Sheikh Najjar Industrial City), Homs (Hessia Industrial City),<sup>13</sup> Damascus (Adra Industrial City) and Deir-ez-Zor. Unfortunately, these industrial cities failed to attract significant foreign direct investment because manufacturing was not as attractive to investors as oil, real estate, trade or services (all of which already made up the majority of foreign investments).<sup>14</sup>

The growth fueled by the state's economic liberalization efforts could not outpace population growth, causing higher levels of unemployment. The proportion of the country's employed working-age population declined during the decade, dropping by 13% (from 45% in 2000 to 39% in 2010). Further, youth unemployment was significant and persistent, with an annual average of 19% from 2000 to 2010.<sup>15</sup> A large part of the rise in unemployment was the severe contraction

of the agricultural sector throughout the decade, with the proportion of workers employed dropping from 33% in 2000 to 13% in 2011.<sup>16</sup> This was driven by significant droughts from 2006 to 2011 as well as more concentrated land ownership, which reduced the labor force through increased economies of scale.<sup>17,18</sup> This produced a significant migration from rural areas to major urban areas, and contributed to the increase in the proportion of employment in the service sector (14 percentage points) from 2000 to 2011.<sup>19</sup>

Poverty and inequality had been persistent issues in Syria despite the decade of economic growth. Though the Human Development Index marginally increased from 0.6 to 0.68 from 2000 to 2011 (comparable to Egypt),<sup>20</sup> Syria had been becoming more and more unequal throughout the decade; the proportion of employed people who live on less than \$3.20 per-day (in purchasing power parity terms) increased by about 14% during the decade before the conflict, from 15.6% in 2000 to

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<sup>11</sup> European University Institute, [The political economic context of Syria's reconstruction: a prospective in light of a legacy of unequal development](#), December 2018.

<sup>12</sup> The World Bank, [Economic Challenges and Reform Options for Syria: A Growth Diagnostics Report](#) (CEM, First Phase), February 2011

<sup>13</sup> SANA, [Hessia Industrial City is a pillar of industry and a main supplier of national economy](#), March 2019.

<sup>14</sup> European University Institute, [Syria's manufacturing sector: the model of economic recovery in question](#), May 2019.

<sup>15</sup> [FRED, Youth Unemployment Rates](#)

<sup>16</sup> World Bank Data, [Employment in agriculture \(% of total employment\) Syrian Arab Republic](#), January 2019

<sup>17</sup> European University Institute, [The political economic context of Syria's reconstruction: a prospective in light of a legacy of unequal development](#), December 2018.

<sup>18</sup> World Bank, [The toll of war: The economic and social consequences of the conflict in Syria](#), 2017.

<sup>19</sup> The World Bank, [Employment in services \(% of total employment\) \(modeled ILO estimate\) - Syrian Arab Republic](#), [updated regularly].

<sup>20</sup> UNDP, [Human Development Index \(HDI\)](#), [updated regularly].

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29.5% in 2011.<sup>21</sup> Multidimensional poverty (which encompasses all deprivations poor people experience, including poor health, lack of education and disempowerment) was relatively high in Syria, at 7% in 2009, comparable to Egypt (6% in 2008), but much higher than Jordan (2.4% in 2009).<sup>22</sup> Poverty in Syria is generally more prevalent in rural areas than urban areas, but the highest poverty rates before the conflict were found in northeast Syria (Aleppo and Ar-Raqqa) and the lowest poverty rates were found in the central and coastal regions (Damascus and Tartous).<sup>23</sup>

## SYRIA'S CONFLICT-ECONOMY

The conflict has created a new set of challenges for businesses in Syrian government-held areas. Many Syrian business owners, mostly from Aleppo, relocated their operations abroad to avoid the conflict and political ramifications of opposing the government during the uprising, particularly textile manufacturing to Egypt and wholesale trading to Turkey.<sup>24</sup> The pharmaceutical sector, which rapidly expanded in the 2000s through investment,

has been hit particularly hard during the conflict as a result of damaged production plants and difficulties replacing and repairing imported physical capital or production inputs as a result of international sanctions.<sup>25</sup> In general within manufacturing, higher production costs, particularly those incurred from more expensive fuel and additional fees and bribes at checkpoints, have inhibited economic expansion.<sup>26</sup> Specific licenses are also needed to produce goods in Syrian government-held areas, which slows production and causes business owners financial planning difficulties. The expansion of the Syrian economy is also slowed by low levels of human capital due to most of the population missing many years of schooling and skilled laborers fleeing the country. Further, business development remains stifled by corrupt government institutions that lack public accountability.<sup>27</sup>

As of 2021, the economy of Self-Administration-controlled areas in eastern Aleppo, Al-Hasakah, and Deir-ez-Zor governorates, is centered on oil and gas production and agriculture exports.<sup>28</sup> Oil and gas production remains the most lucrative sector, despite production slowdowns from

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<sup>21</sup> UNDP, [Human Development Reports](#). [updated regularly].

<sup>22</sup> OPHI, [Data tables and Do-files](#). [updated regularly].

<sup>23</sup> UNDP, [Poverty in Syria: 1996-2004. Diagnosis and pro-poor policy considerations](#). June 2005.

<sup>24</sup> European University Institute. [Syria's manufacturing sector: the model of economic recovery in question](#). May 2019.

<sup>25</sup> *Ibid.*

<sup>26</sup> Zakaria, A. [Aleppo merchants and workshops ... and the "curse" of military security](#). August 2020.

<sup>27</sup> IMF WP/16/123. [Syria's Conflict Economy](#). June 2016.

<sup>28</sup> European University Institute, [The Political Economy of the Autonomous Administration of North and East Syria](#). November 2019.



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violence and difficulties repairing wells and related infrastructure. The Self-Administration government lacks formal refineries, though small informal refineries are prevalent in the region.<sup>29</sup> It generally sells crude oil across the border to Iraqi Kurdistan<sup>30,31</sup> and also supplies oil internally to government-held areas.<sup>32</sup> The northeast remains the “breadbasket of Syria” and produces ample wheat harvests, but poultry and sheep are principally exported to Iraqi Kurdistan and Turkey for higher prices.<sup>33,34</sup> Local manufacturing remains underdeveloped, consisting of small operations that only employ a few hundred people producing textiles, cosmetics, paper towels, shampoo, soap, among other items.<sup>35</sup> The sector suffers from a lack of capital, difficulty importing raw materials, and the administration’s lack of appropriate certificates of origin or quality, which hinder the potential for export.

Turkey currently controls large parts of northwest Syria as a result of Operation Olive Branch in 2018 (which came after Euphrates Shield in the northeast, in which

Turkey also took control of border territory), and holds deep economic ties with the opposition-held portions of the region. Cross-border commercial activity supports many traders, businessmen, and smugglers, the latter of whom are centered on smuggling lower-cost Syrian oil to Turkey at a profit.<sup>36</sup> Further, many legitimate businesses in the northwest re-established themselves in Turkish-controlled areas and in Turkey along the border.<sup>37,38</sup> As a result, a significant amount of economic power in the region has shifted from Aleppo to several towns bordering Turkey.

In this report, we measure the real GDP of three geographic aggregations. First, by zone of control to assess the relative economic size of each regional administration. Second, at the governorate-level to examine the growth dynamics and relative economic significance of larger regions during the conflict. Third, at the subdistrict-level to more precisely analyze changes in the geographic distribution of economic activity within Syria, particularly as it relates to the effects of the conflict.

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<sup>29</sup> Middle East Eye, [Life inside Syria's makeshift oil refineries](#), February 2015

<sup>30</sup> Al-Monitor, [Kurdish forces agree to deliver oil, Syrian regime reopens crossings](#), April 2021.

<sup>31</sup> European University Institute, [The Political Economy of the Autonomous Administration of North and East Syria](#), November 2019.

<sup>32</sup> Chatham House, [Implications of the Oil Deal for the Kurds in Syria](#), September 2020

<sup>33</sup> European University Institute, [The Political Economy of the Autonomous Administration of North and East Syria](#), November 2019.

<sup>34</sup> Mercy Corps. Al-Hasakeh, Syria agricultural assessment. October 2015.

<sup>35</sup> European University Institute, [The Political Economy of the Autonomous Administration of North and East Syria](#), November 2019.

<sup>36</sup> Tokmajyan, A. [The war economy in northern Syria](#), December 2016.

<sup>37</sup> Karaspan, T. [Challenges facing Turkey's Syrian businesses](#), March 2021.

<sup>38</sup> Brookings. [Syrian Entrepreneurship and Refugee Start-ups in Turkey: Leveraging the Turkish Experience](#), 2018.

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# PART I. NIGHT LIGHTS REFLECTANCE DATA

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## NIGHT LIGHT REFLECTANCE SATELLITE IMAGERY

There are two freely-available sources for night lights imagery, the US Air Force Defense Meteorological Satellite Program Operational Linescan System, hereby referred to as DMSP, and the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the joint NASA/NOAA Suomi National Polar-orbiting Partnership satellite and NOAA-20 satellites. The DMSP instrument collected annual NLRD from 1992 to 2013, and the VIIRS instruments has collected daily night lights reflectance images from April 2012 to the present. The Earth Observation Group produces monthly and annual VIIRS composites, which are processed to remove stray light and biomass fires, remove glow from bright pixels, and isolate radiance from the background.<sup>39</sup>

The DMSP and VIIRS instruments record night light radiance in distinct units at different spatial resolutions. The DMSP measures radiance as digital numbers (DNs) and the VIIRS satellite measures reflectance as proportional to the intensity of light in

nanowatts per-square centimeter per-steradian (nW/cm<sup>2</sup>/sr). The DNs recorded by the DMSP are top-censored, meaning very high reflectance values at and above the maximum recordable reflectance value are all assigned the same maximum DN value. DMSP reflectance data varies among satellites due to unrecorded changes in sensor sensitivity, which requires DN values to be statistically adjusted to create a comparable time series of reflectance values;<sup>40</sup> conversely, VIIRS sensors are calibrated radiometers and do not require any temporal adjustments. Most noticeably, VIIRS pixels are about half (450m<sup>2</sup>) the size of DMSP pixels (1km<sup>2</sup>), which are also subject to significant geolocation errors; specifically, light sources may be located about 3km from the recorded pixel.<sup>41</sup> As a result, reflectance values from both satellites must be specifically processed and analyzed.

VIIRS images are better predictors of economic activity because of the higher spatial resolution, lack of top-coding, and temporally-consistent measurements.<sup>42</sup> DMSP images overstate the expanse of urban areas due to blurring caused by sensor

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<sup>39</sup> Int.Journal of Remote Sensing 38 (21) [VIIRS night-time lights](#), February 2017.

<sup>40</sup> World Bank [github], [1. DMSP-OLS intercalibration \(10 min\) – Open Nighttime Lights](#), 2013

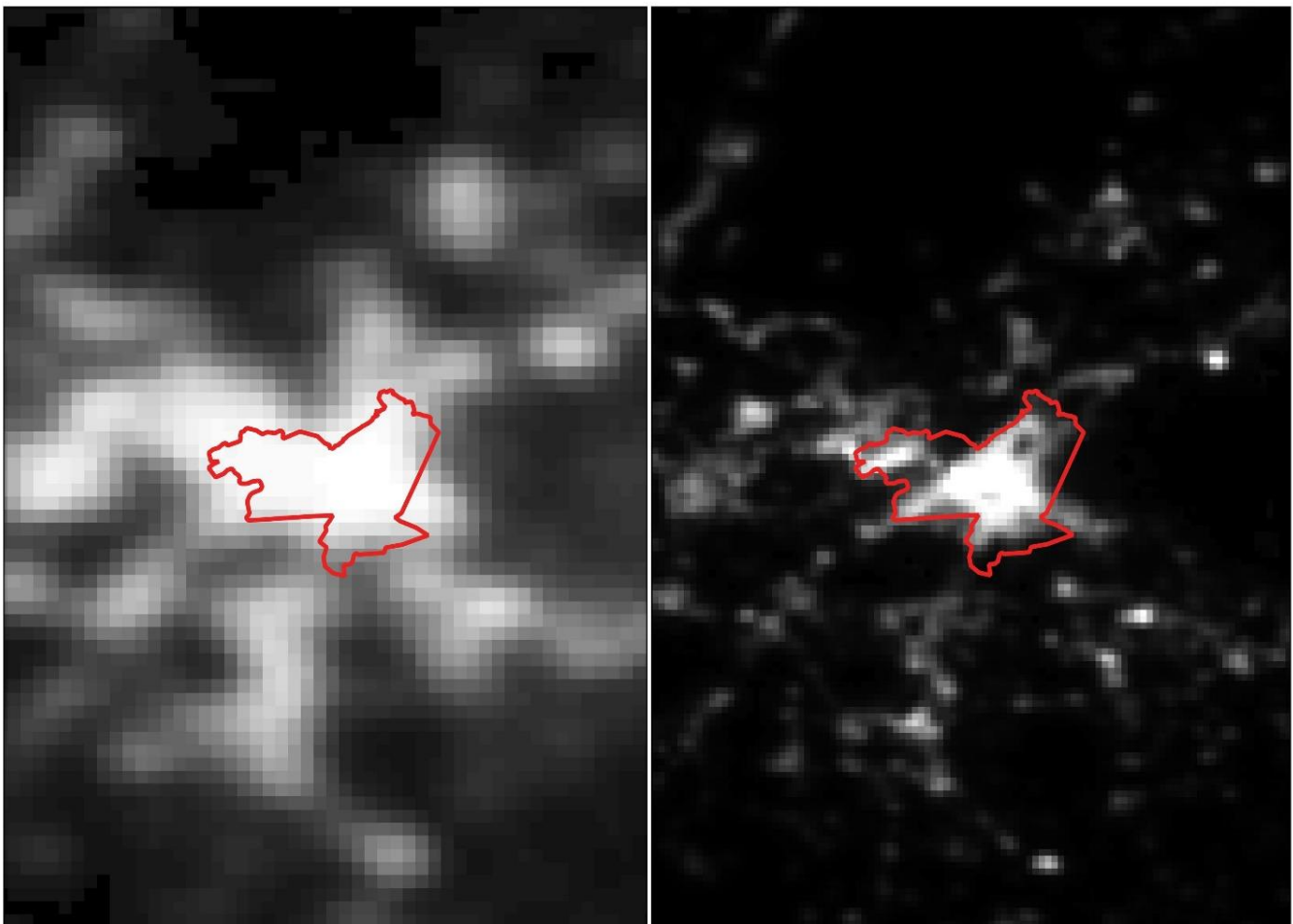
<sup>41</sup> Photogrammetric Engineering & Remote Sensing 79(3), pp. 287-297. [It used to be dark here](#), March 2013

<sup>42</sup> Journal of Economic Surveys, [Night lights in economics: Sources and uses](#), August 2020.

and data management issues,<sup>43</sup> and overflow from bright pixels, and understate the extent of heterogeneity of development within urban areas, especially megalopolises.<sup>44</sup> VIIRS reflectance data is superior at predicting regional GDP in urban areas than DMSP reflectance data, though neither of them are particularly useful for predicting

economic activity in low-density rural areas.<sup>45</sup>

Figure 1 compares DMSP and VIIRS images of Damascus in 2013, and highlights the much lower spatial resolution and problematic overflow effect of DMSP images.



*Figure 1: Night lights reflectance of Damascus using the DMSP (left) and VIIRS (right) satellites in 2013. Notice the finer spatial resolution of the VIIRS image and the large amount of overflow (light spillover) in the DMSP image.*

<sup>43</sup> Remote Sensing of Environment 210(1), [Deblurring DMSP night-time lights: A new method using Gaussian filters and frequencies of illumination](#), January 2016

<sup>44</sup> Journal of Economic Surveys, 34 (5) [Night lights in economics: Sources and uses](#), August 2020.

<sup>45</sup> Journal of Development Economics , 149, [Which night lights data should we use in economics, and where?](#), March 2021.

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# NIGHT LIGHT REFLECTANCE AND ECONOMIC ACTIVITY

Night lights are a particularly useful proxy for a variety of modern human activity, such as urbanization and electricity consumption, and are a useful tool to measure economic activity. This is largely due to the idea relationships between economic activity and night lights reflectance are more reliable and are not the result of shared systematic errors apparent in other data sources (ie, survey errors, bias in estimations, human error, corruption). More broadly, NLRD is the most reliable freely-available data useful for estimating economic activity in developing countries and challenging contexts.

Previously, the data has been used to measure economic activity and growth in other contexts. For example, NLRD was used to predict regional GDP in India and Brazil using DMSP data;<sup>46</sup> however the relationships found between night light reflectance and regional GDP were unstable over time, most likely due to DMSP precision issues.<sup>47</sup> Measurements have also been used to assess the economic benefits gained from

the economic partnership between countries in east Africa, which they found only lasted four years after the partnership and were highly localized to cities near the border.<sup>48</sup> NLRD has also been used to estimate the economic impact of road improvements in Haiti.<sup>49</sup>

Attempts to measure the relationship between GDP and night lights growth has produced mixed results.<sup>50</sup> Studies have found that VIIRS luminosity data only explained 30% to 40% of the variation in output data in sub-Saharan Africa, which is still more than measurements using DMSP imagery.<sup>51</sup> Further, VIIRS imagery is useful for cross-section GDP levels, however, growth estimates are.<sup>52</sup> Consequently, it may be a good indicator for static measurements, and not to assess changes in economic output over time.

A major limitation with estimating economic activity is that the economic value of light differs by industry. For example, the lights illuminating a large sporting event are far brighter than headquarters developing innovative technology. NLRD and GDP therefore represent different aspects of economic activity; specifically, GDP is a

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<sup>46</sup> Kiel Institute for the World Economy, [Night lights and regional GDP](#). December 2013.

<sup>47</sup> Journal of Development Economics (149), [Which night lights data should we use in economics, and where?](#) March 2021.

<sup>48</sup> Journal of Development Economics (140), [Regional market integration in East Africa: Local but no regional effects?](#) September 2019.

<sup>49</sup> Inter American Development Bank, [Measuring the impact of transport infrastructure using luminosity data in Haiti](#). December 2018

<sup>50</sup> Kiel Institute for the World Economy, [Night lights and regional GDP](#). December 2013.

<sup>51</sup> Remote Sensing 7(4) pp. 4937-4947, [A Test of the New VIIRS Lights Data Set: Population and Economic Output in Africa](#) April 2015.

<sup>52</sup> Remote Sensing 11(9), pp 1057, [VIIRS Nighttime Lights in the Estimation of Cross-Sectional and Time-Series GDP](#). May 2019.

better measure of technological innovation and industrialization, and NLRD is a better indicator of population growth, foreign direct investment, and resource consumption.<sup>53</sup> This issue is much less relevant in Syria because the economy lacks an advanced technology sector and is centered on manufacturing and extraction industries which generate large amounts of light. However, the questionable capability of night lights to measure the economic contribution of agriculture and other low-energy sectors raise concerns, as they comprise a large proportion of Syria's economy.<sup>54,55</sup>

The data may also be useful for monitoring humanitarian conditions in dangerous and difficult contexts. Specifically, related to changes in security conditions and occupying forces, the data has been applied in the context of Iraq, finding significant changes in economic activity in areas held by Iraqi Security Forces and ISIS. Findings revealed that reflectance levels dramatically declined

in ISIS-controlled regions compared to regions controlled by the Iraqi Security Forces.<sup>56</sup> This could be applied to a range of contexts in Syria, to areas formerly occupied by ISIS or to areas under the control of other armed actors or administrations (for example, areas annexed by Turkey, or potentially where armed actors like Hay'at Tahrir al Sham (HTS) are known to operate).

While NLRD has been used to monitor changes over the course of the Syrian civil war at national, subnational, and urban geographies, no previous study has estimated regional economic output using this data.<sup>57,58</sup> Corbane et al. used VIIRS imagery to estimate the number of people affected by the Syrian conflict and evaluated the spatial dynamics of night light reflectance within affected cities.<sup>59</sup> It found that NLRD had potential applications for the assessment of populations in crisis – useful for humanitarian contexts. This study builds on this, using similar tools to assess economic activity and growth.

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<sup>53</sup> Frontiers in Physics, [Regional Economic Convergence in China: A Comparative Study of Nighttime Light and GDP](#). April 2021.

<sup>54</sup> World Development, (66) pp., 322–334. [Monitoring economic development from space: Using nighttime light and land cover data to measure economic growth](#). February 2015.

<sup>55</sup> Journal of Economic Surveys, [Night lights in economics: Sources and uses](#). August 2020.

<sup>56</sup> Int. Journal of Remote Sensing 36 (13), pp. 3446–3458, [Detecting 2014 Northern Iraq Insurgency Using NightTime Light Imagery](#). June 2015.

<sup>57</sup> Int. Journal of Remote Sensing 35 (18), pp. 6648–6661, [Can Night-Time Light Images Play a Role in Evaluating the Syrian Crisis?](#) September 2014

<sup>58</sup> Int. Journal of Remote Sensing, 38, pp. 5934–5951, [Intercalibration between DMSP/OLS and VIIRS night-time light images to evaluate city light dynamics of Syria's major human settlement during Syrian Civil War](#). October 2016

<sup>59</sup> European Commission JRC Technical Report, [Monitoring the Syrian Humanitarian Crisis with the JRC's Global Human Settlement Layer and Night-Time Satellite Data](#). 2016

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## PART II. ESTIMATING REGIONAL GDP

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### DATA

Night light reflectance imagery was collected from a depository organized by the Colorado School of Mines' Earth Observation Group.<sup>60</sup> For this analysis, we use the annual DMSP images from 1992 to 2013 and annual VIIRS images from 2012 to 2020; the VIIRS annual composites discards detected biomass fires and isolates electricity-produced radiance in monthly images and then aggregates the corrected images into annual composites.<sup>61</sup> We applied the VIIRS annual lit area mask, which is a binary indicator of consistent light emission from each pixel, to filter out unreliable night light reflectance (for example fires and cloud reflectance). Due to the use of different satellites over time, the DMSP time series was inter-calibrated to harmonize digital number values, according to the procedure and calibrations estimates provided by the World Bank.<sup>62</sup> Further, images produced by the most recent satellite were used if multiple satellites were available for the same year.

The CIA and Penn World Table 10.0 are the only public sources for real GDP estimates

for Syria. The CIA produced real GDP estimates from 2013 to 2015,<sup>63</sup> and the Penn World Table estimates are available until 2019.<sup>64</sup> The CIA estimates are more in line with the last World Bank estimate in 2007.<sup>65</sup> Specifically, the CIA's real GDP estimate for 2013 was \$60.9 billion and the World Bank estimate for 2007 was \$40.4 billion. Given that Syria's economy was growing by an average of 12% from 2000 to 2007 (according to World Bank estimates), the World Bank's 2010 real GDP estimate would be about \$64 billion, very close to the 2013 CIA estimate (\$61.9 million). The Penn World Table 10.0 real GDP estimates were dramatically larger, with an estimated 2010 real GDP of about \$265 billion. Despite these unrealistic estimates, we chose to use the Penn World Table statistics because the dataset has the most complete time series. However, we adjusted the Penn World Table estimates by the average proportion difference between the Penn World Table estimates and CIA estimates from 2013–2015, which were nearly the same each year (42%). Therefore, we maintained the time trend from the Penn World Table while

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<sup>60</sup> EOG data, [Index](#).

<sup>61</sup> EOG data, [Annual VNL V2](#).

<sup>62</sup> World Bank [github], [1. DMSP-OLS intercalibration \(10 min\) – Open Nighttime Lights](#)

<sup>63</sup> CIA, [Real GDP \(purchasing power parity\) - The World Factbook](#)

<sup>64</sup> Economic Research, [Real GDP at Constant National Prices](#)

<sup>65</sup> World Bank Data, [GDP \(current US\\$\) - Syrian Arab Republic | Data](#)

applying a numerically reasonable real GDP estimate.

We forecasted Syria's 2020 real GDP estimate by fitting the Penn World Table real GDP statistics for Syria from 1960–2019 to five exponential smoothing models using the AWS SageMaker cloud-based machine-learning platform. SageMaker selected the statistically optimal model, which forecasted a 2020 GDP of \$123.79 billion. After applying our 42% reduction factor, the estimated 2020 GDP was \$51.9 billion. Further, assuming the Syrian economy shrank by \$1 billion per month from March to

April 2020 as a result of the COVID-19 lockdowns,<sup>66</sup> and given the lockdowns ended in late May 2020,<sup>67</sup> we deducted \$3 billion from the previously-adjusted figure for a final 2020 GDP estimate of \$48.9 billion.

## SPATIAL DISAGGREGATION

The GDP disaggregation procedure closely follows the methodology established by Zhao et al.,<sup>68</sup> who disaggregate GDP according to the proportion of night light reflectance per pixel. Following their methodology, we

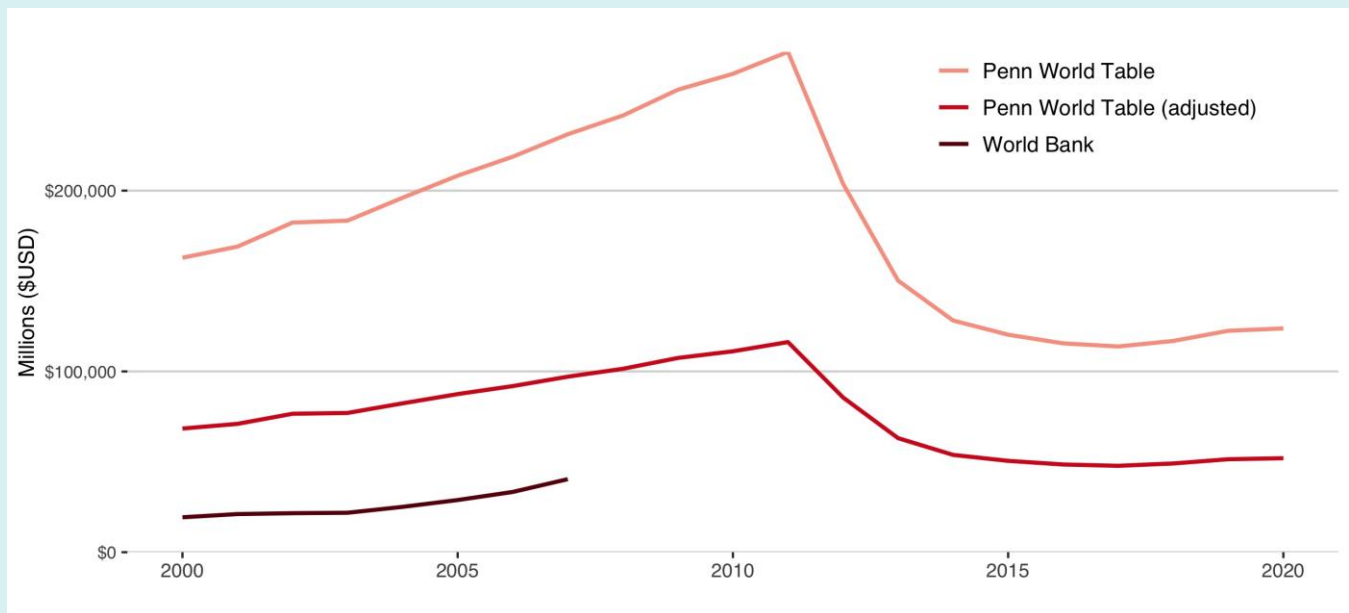


Figure 2: Notice the Penn World Table estimates, even the adjusted estimates that are used for this analysis are much larger than the more widely-cited World Bank real GDP estimates. World Bank real GDP estimates are only available until 2007. Note that Penn World Table estimates for 2020 are derived from the estimation method developed by HAT and detailed in the text.

<sup>66</sup> Friedrich Ebert Stiftung, [COVID-19 and the Syrian economy](#), July 2020

<sup>67</sup> SANA, [Curfew and restriction of movement among provinces lifted as of Tuesday May 26th](#), May 2021

<sup>68</sup> GIScience & Remote Sensing, 54 (3), [Forecasting China's GDP at the pixel level using nighttime lights time series and population images](#). January 2017

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calculated the population-density weighted proportion of night lights reflectance per pixel, taking into account the pixel's share of night light reflectance and the estimated local population density. We used WorldPop UN-adjusted constrained population density estimates,<sup>69</sup> which provides population density estimates within 1km<sup>2</sup> grid cells. The population density grid cell center point nearest to a night light image pixel was assigned as the local population density estimate. This means if two pixels exhibit the same night lights reflectance but different local population densities and therefore agglomeration economies, then the pixel with a higher population density will have a larger GDP.

We transformed the population density estimates to limit the weight of extremely large population density values, which distorted GDP estimates towards urban centers. The natural log was used to transform the population density data, reshaping the right-skewed distribution more like a normal distribution. Regional GDP statistics do not exist for any time period; therefore, the disaggregation results are guided by the common understanding that Aleppo was the economic center of Syria

before the conflict,<sup>70</sup> and Rural Damascus is likely the largest regional economy for most of the conflict (post-2014), meaning valid disaggregation places Aleppo and Rural Damascus as the largest regional economies during those time periods.

The higher spatial resolution of the VIIRS satellites provides more detailed NLRD; therefore, VIIRS disaggregations were used as the benchmark to assess the DMSP disaggregations in 2012 and 2013, the only years the two satellites both recorded images.<sup>71</sup> A series of *n*th root data transformations were applied to population density values until one produced a regional real GDP disaggregation statistically indistinguishable from the VIIRS disaggregation.<sup>72</sup> Given that the conflict began in 2012 and is contextually closer to the decade prior than 2013, when the conflict escalated, the DMSP population density weighting factor for 2012 was used to process the annual images from 2000 to 2012.<sup>73</sup>

Extremely high VIIRS reflectance values, all representing oil and gas flares, were censored to a lower (but relatively very high) reflectance value to avoid overestimating the

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<sup>69</sup> WorldPop, [Population Density](#)

<sup>70</sup> Syrian Observer, [What Has Syria Lost With the Destruction of Aleppo?](#) Syrian Observer, 2016.

<sup>71</sup> We chose not to convert VIIRS values to DN# because the loss of information due to top coding is too great; specifically, underestimating the contribution of the energy sector.

<sup>72</sup> If more than one transformation produced disaggregation statistically identical to the VIIRS disaggregation, the one with the highest correlation coefficient was chosen.

<sup>73</sup> The 2012 population density weighting factor was 0.7 with a correlation coefficient of 0.94, and the 2013 population density weighting factor of 0.8 that produced a correlation coefficient of 0.84.



economic output of these activities. Gas flare reflectance and oil production are closely related; therefore, censoring gas flare reflectance roughly represents the economic contribution of oil production.<sup>74,75</sup> The maximum possible reflectance value is defined as the maximum reflectance value generated in Israel, a developed country with scarce oil and gas production.<sup>76</sup> The step operates under the assumption that the brightest oil and gas flares, representing energy production, are as economically valuable as dense urban areas (for example, Tel Aviv).

This is admittedly contestable, but is compensated by the relatively few concentrated high-reflectance pixels that are produced by oil and gas wells in comparison with the large swaths of high-value pixels recorded in urban centers. Significant growth in night lights reflectance in Homs governorate from 2016 to 2017 were set to half of the 2018 reflectance value to avoid overestimating oil production – those pixels do not represent the expansion of production, but rather intense oil well fires ignited by ISIS while they retreated during a

major Syrian government offensive in the governorate.<sup>77</sup>

## NIGHT LIGHT-CORRECTED REGIONAL GDP

Night light-corrected GDP estimates were calculated according to the methodology established by Hu and Yao for the International Monetary Fund.<sup>78</sup> This method is based on the concept that the true value of GDP lies between the GDP predicted by night light reflectance and official GDP estimates; night lights are a reliable indicator of economic activity that feature measurement errors independent of those produced during the collection and calculation of official GDP estimates. In essence, the procedure estimates the optimal combination of predicted and observed values of real GDP. The weighting factor between the two statistics depends on the distribution of measurement errors in official GDP estimates and night light reflectance data. The authors defined the distribution of night lights measurement error using a country's latitude, and the distribution of official GDP measurement errors using the

<sup>74</sup> IMF Working Paper 19/221, [Assessing Oil and Non-Oil GDP Growth from Space: An Application to Yemen 2012-17](#), October 2019.

<sup>75</sup> World Bank, [How Much Oil is the Islamic State Group Producing? Evidence from Remote Sensing](#), Policy Research Working Paper 8231, October 2017.

<sup>76</sup> Following the procedure of Li, X., R. Zhang, C. Huang, and D. Li. 2015. [Detecting 2014 Northern Iraq Insurgency Using NightTime Light Imagery](#), International Journal of Remote Sensing 36 (13): 3446–3458.

<sup>77</sup> New China, [Syrian army captured key oil field near Palmyra](#), March 2017

<sup>78</sup> IMF, [Illuminating Economic Growth](#) by Yingyao Hu and Jiaxiong Yao, April 2019

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World Bank-defined statistical capacity. The methodology was developed for country-level data, which requires data unavailable at the subnational level; however, one of the authors recommended applying the typical country-level correction factor for real GDP predictions produced by DMSP (0.4) and VIIRS (0.6) images.<sup>79,80</sup>

The correction factor is applied to a simple linear function that requires a real GDP prediction generated by a regression predicting real GDP using night light reflectance statistics.<sup>81</sup> We tested two regression models using different independent variables representing the distribution of night light reflectance; (i) the mean night light reflectance, and (ii) the median reflectance value and standard deviation of reflectance values.

The latter model is inspired by the fact that night light reflectance values are right-skewed at all levels of spatial disaggregation; therefore, the median, and not the mean, represents the ‘typical’ regional reflectance value, and the mean night light reflectance is roughly the median value plus a measure of dispersion from the mean (standard deviation). The squared mean night light reflectance values was also added as an independent variable in the mean-only model

to test for a possible quadratic relationship between mean reflectance values and real GDP.

Regressions using subdistrict data are compared to regressions using the national level for the DMSP and VIIRS time series. The national-level baseline regression adds a sequential numeric variable to account for the time trend, and regional regressions are estimated using panel data regression models, which account for region-specific and time trends.<sup>82</sup> The spatial disaggregation procedure is assumed to be reasonable if the national and subdistrict models produce similar goodness of fits and coefficients because it indicates that the integrity of the relationship between night lights reflectance and real GDP is maintained.

The national- and subdistrict-level VIIRS regressions fit the data about equally well, but the DMSP data predicted real GDP at the national level far better than the subdistrict level. DMSP night lights reflectance only explained 43% of the variation in regional GDP, but explained about 91% of the variation in national GDP over time. The VIIRS reflectance values explained comparable proportions of variation in subdistrict (94%) and national (93%) real GDP, indicating that VIIRS images are much

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<sup>79</sup> Personal communication.

<sup>80</sup> A sub-national measurement error correction procedure is drafted, but the methodology should be first peer-reviewed and published in an academic journal before application; therefore, we followed the author of the methodology’s recommendation.

<sup>81</sup> Page 14, equation 5 of [Illuminating Economic Growth](#) by Yingyao Hu and Jiaxiong Yao, International Monetary Fund, 2019.

<sup>82</sup> The choice between fixed or random effects is decided by the statistical significance of the Hausman test.

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better suited for the disaggregation procedure than DMSP, and there was no loss of information during the disaggregation procedure.

We compared the final adjusted real GDP estimates produced using VIIRS and DMSP reflectance data at the subdistrict-level and governorate level for 2012 and 2013. The 2012 and 2013 subdistrict-level VIIRS and DMSP estimates were highly to moderately correlated (0.86; 0.68), but paired t-tests indicated the estimates were statistically

significantly different according to paired t-tests, with DMSP estimates about 2% larger than the VIIRS estimates in 2012 and approximately 8.5% larger than the VIIRS estimates in 2013. The 2012 and 2013 subdistrict estimates aggregated to the governorate-level, were highly correlated (0.90; 0.77), and not statistically significantly different, according to paired t-tests. Due to these mixed results, the real GDP estimates generated by each satellite are analyzed separately and distinctly labeled in graphs.

# PART III. ANALYSIS

## ZONES OF CONTROL

Real GDP estimates were aggregated according to the zone of control that the center of the subdistrict fell into. The lines of control shifted considerably throughout the conflict, however have stabilized since March 2020. Table 1 provides the economic value of each zone of control.

Syrian government-held areas had the highest total GDP; largely from the country's industrial sites with the territory, and significant oil and gas wells in western Deir-ez-Zor and Homs. The higher per-capita income in Self-Administration-held areas can

be attributed to a smaller population, significant oil rents bolstered by exports to Iraqi Kurdistan and the Syrian government, and urban development driven by the large number of internally displaced people.<sup>83,84</sup> Turkish-controlled areas had significantly lower per capita income, however were underdeveloped even prior to the conflict. Finally, opposition-controlled areas had the lowest per capita income, largely caused by stagnant economic output, compounded by the prevalence of acute violence, and the extremely large number of internally-displaced people, most of which are unproductive due to few employment opportunities.<sup>85</sup>

Zone of control	GDP (millions, \$USD)	Share of national GDP	Per-capita GDP (\$USD)	% of total population	% of total area (sqkm)
Syrian government	37,984	67.5%	2,773	65.9%	69.1%
Self-administration	16,693	29.7%	6,781	11.8%	24.4%
Turkish-controlled	1,112	2.0%	772	6.9%	4.6%
Opposition-controlled	503	0.9%	164	15.3%	1.8%

*Table 1: GDP by zone of control, 2020. Identification determined by the zone of control where the subdistrict's center point is located.*

<sup>83</sup> Iraqi Oil Report, [Oil exports into Iraqi Kurdistan give Syrian Kurds a financial lifeline](#). February 2020.

<sup>84</sup> Al-Monitor, [Syrian government, SDF trade accusations of violations of Russian-mediated cease-fire](#). Feb 2021.

<sup>85</sup> Al-Monitor, [French NGO provides temporary jobs for Syrians in the northwest](#). March 2021.

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## GOVERNORATES

Governorate-level real GDP estimates (shown in Figure 2), follow the economic dynamics outlined in national analysis. As was the case for Syria at the national level, real GDP grew in a positive linear fashion across all governorates until the beginning of the conflict. The economy of Deir-ez-Zor experienced the slowest rate of growth from 2000 to 2011, highlighting the economic trouble experienced by the region due to lack of investment, drought, and significant rural-urban migration. Growth rates were highest among governorates with major urban centers, (those of Aleppo, Homs, Rural Damascus and Damascus), indicative of the large investments in 'industrial cities' and urban development during the period of market liberalization (in the mid 2000s).

The growth trends during the conflict coincide with notable geopolitical milestones. The real GDP of Aleppo governorate fell by 85% from 2012, when it fell to the opposition, until Syrian government forces regained control of the city in late 2016. The real GDP of Homs governorate grew for the first several years of the conflict, likely due to its position as a lucrative crossing point between Lebanon,

Syrian government-controlled areas, and opposition-controlled areas, modest oil production under ISIS control in 2014 and 2015,<sup>86</sup> and the low-level damage Hama sustained (compared to other cities in the northwest, such as Idleb and Aleppo).<sup>87</sup> However, the economy began to decline in 2016 when Syrian government forces began an offensive against ISIS occupation – on retreat from Homs, ISIS then set fire to its oil wells, reducing its economic capacity.

Idleb was the second-smallest governorate economy in 2012 (behind Quneitra), and had continued to grow slowly since the battle for Idleb in 2015, but was then again negatively affected by the 2019 offensive. Deir-ez-Zor has rebounded to nearly pre-conflict economic output since the Syrian government and Self-Administration took control of the oil wells in late 2017. Al-Hasakeh governorate has economically expanded, growing past its 2012 rate of GDP in 2018, likely due to increased housing construction and the associated service provision to accommodate the influx of internally displaced people.<sup>88,89</sup> Oil and gas production also appears to have returned to at least pre-conflict levels since the governorate was taken by the Self-Administration in 2016.

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<sup>86</sup> The World Bank. [How Much Oil is the Islamic State Group Producing? Evidence from Remote Sensing](#). August 2019.

<sup>87</sup> The World Bank. [Syria damage assessment of selected cities Aleppo, Hama, Idlib](#). March 2017.

<sup>88</sup> Enab Baladi, [Solutions to limit the rise in housing rents in Autonomous Administration's areas](#), January 2018

<sup>89</sup> Al-Hasakeh governorate was contains the four-highest number of internally-displaced people in Syria since 2016, as of February 2021 using data from OCHA: [Syrian Arab Republic: IDP movements and IDP spontaneous return movements Data](#)

The economy of Quneitra has grown past its pre-conflict level, especially since the government regained control of the governorate in 2018, likely due the high number of returnees, the significant UNDOF presence and general redevelopment by residents and returnees.<sup>90</sup> The growth patterns of Dar'a and As-Sweida are similar, with real GDP recovering in 2020 to approximately 20% less than 2012 levels. Damascus, Latakia, and Tartous are experiencing a steady economic decline, perhaps due to lower state revenues and the

frozen capital as a result of sanctions and, more recently, the Syrian financial crisis. The real GDP of Rural Damascus declined by 56% from 2012 until late 2015 when returned to Syrian government control; since then its economic recovery has been positive but volatile.

## SUBDISTRICTS

The spatial distribution of real GDP at the subdistrict level followed the expected economic geography of Syria and remained consistently spatially concentrated before

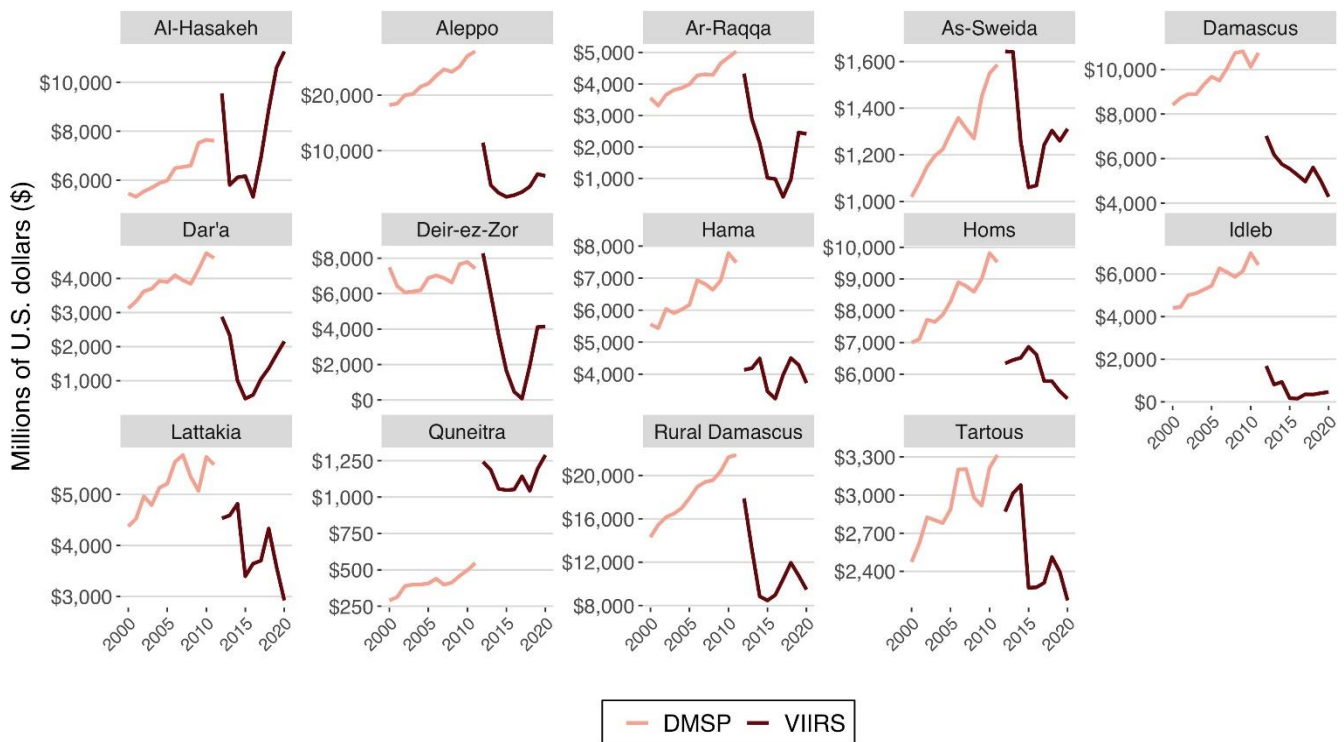


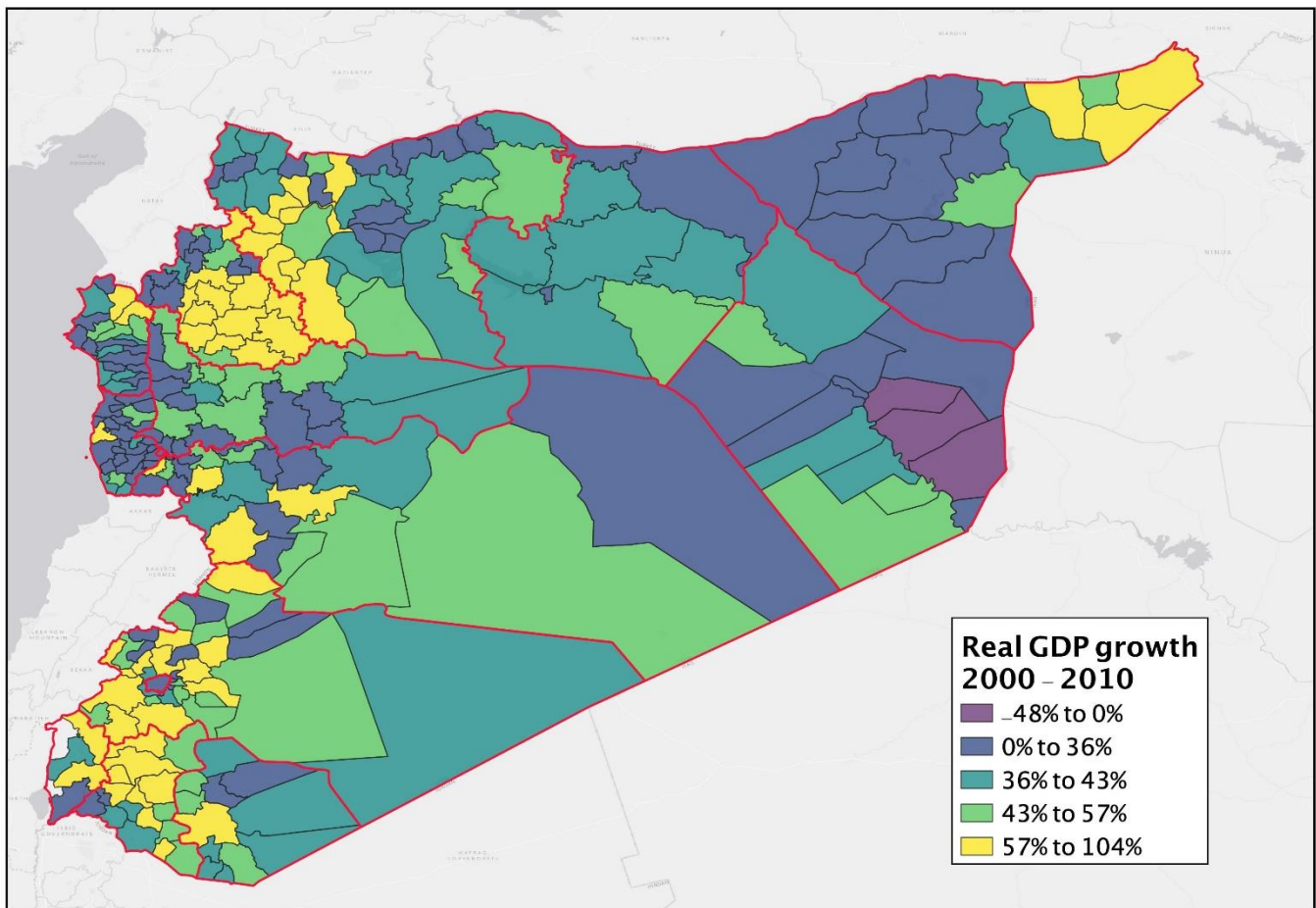
Figure 3: Governorate-level GDP, 2000-2020. DMSP estimates (2000-2011) are shown in red, and VIIRS estimates (2012-2020) are shown in blue. Inter-governorate comparisons are only valid between estimates produced by the same satellite; however, trendlines may be compared between satellites.

<sup>90</sup> Arab News. [UN peacekeepers return to Golan Heights](#). August 2018.

and after the conflict.<sup>91</sup> Figure 4 shows the long-run GDP growth from 2000 to 2010. During this period, Deir-ez-Zor and Quneitra were the only governorates with subdistricts that experienced negative economic growth; further, a large proportion of Al-Hasakeh experienced marginal positive growth, consistent with reports of high poverty in the eastern half of the country.<sup>92</sup> Growth

occurred mainly in urban subdistricts around Aleppo and Damascus.

Subdistricts in Eastern Homs, Deir-ez-Zor, western Aleppo, and Idleb experienced the sharpest regional decline in real GDP due to the conflict and occupation by ISIS. However, subdistricts in Damascus and Rural Damascus also experienced significant economic decline, perhaps an indication that the region has not economically recovered



*Figure 4: Estimated subdistrict real GDP 2000-2010 growth rates. Estimates generated using annual DMSP night light reflectance data.*

<sup>91</sup> Based on statistically significant Moran's I statistics, which measures the level of spatial clustering (spatial autocorrelation), calculated from real GDP level and real GDP growth rates for each year of the time series.

<sup>92</sup> IMF WP/16/123. [Syria's Conflict Economy](#). June 2016.

from the intense violence and significant destruction at the beginning of the conflict.

Economic growth is noticeably concentrated near international borders with Lebanon, Turkey and Jordan, and between Syrian government and opposition-controlled areas in western Hama. This suggests that economic power in Syria has shifted from large urban centers to strategically-located border regions centered on cross-border economic activities, particularly legal and

illegal trade. Several subdistricts along the Turkish border were among the fastest-growing regional economies during the conflict. Atareb is a prime example, where business has thrived and the standard of living has risen over the course of the conflict. The economy of Sarmada also expanded due to its position as a hub for goods imported from or through Turkey, and has attracted investment in infrastructure: an example of this is seen in electrical infrastructure,

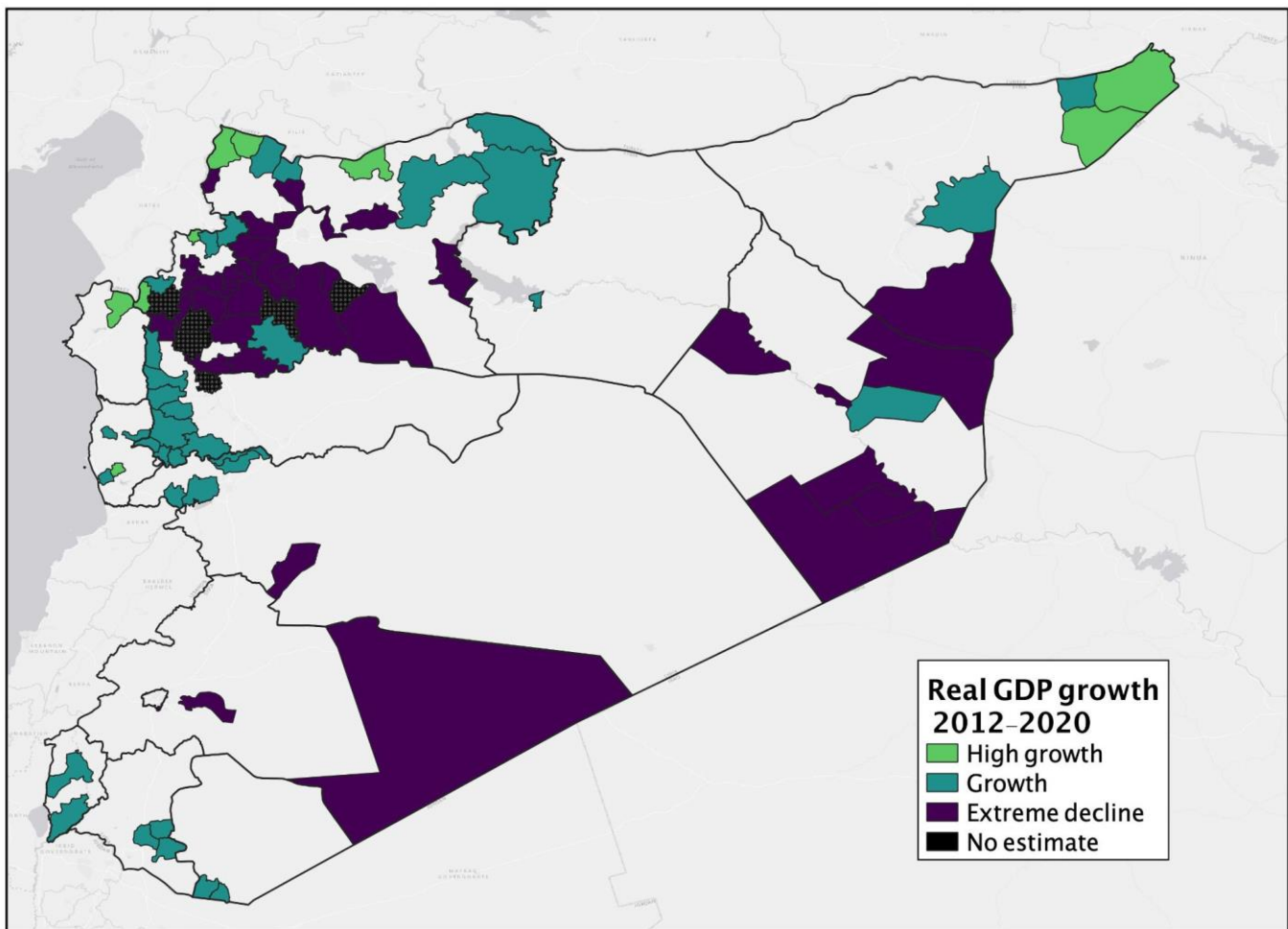


Figure 5: Estimated subdistrict real GDP 2012-2020 growth rates. Estimates generated using annual VIIRS night light reflectance data.



whereby a private company provides electricity to 90% of the residents.<sup>93</sup>

The importation of construction materials is another thriving business along the Turkish border, as residents and returnees rebuild in areas where violence has ceased. The cities of Al-Dana, Atareb and Azaz in particular are large markets for construction materials. Food markets stocking imported and local

produce are the most significant cross border economic activity, with the largest wholesale food markets located in Al-Dana, Armanaz, Salqin, and Atareb, in sequential order.<sup>95</sup> Small-scale informal oil refineries were common in Al-Dana, Atareb, Salqin, Sarmada, and Azaz, particularly to process oil extracted by ISIS at the time when the group controlled the eastern oil-producing regions, and particularly when their mobile wells

	DMSP-OLS			VIIRS		
	2000 GDP (millions, \$USD)	2010 GDP (millions, \$USD)	GDP growth, 00-10	2012 GDP (millions, \$USD)	2020 GDP (millions, \$USD)	GDP growth, 12-20
Damascus	8,412	10,128	20%	7,020	4,279	-39%
Aleppo <sup>94</sup>	11,382	16,838	48%	5,984	2,383	-60%
Homs	4,080	5,651	38%	2,043	1,726	-16%
Hama	2,468	3,594	46%	1,808	1,769	-2%
Al-Hasakeh	1,397	1,886	35%	1,372	770	-44%
Idleb	576	907	57%	396	25	-94%
Ar-Raqqa	1,691	2,324	37%	2,185	1,069	-51%
Latakia	2,070	2,587	25%	1,825	980	-46%

*Table 2: GDP estimates for major Syrian urban subdistricts*

<sup>93</sup> Tokmajyan, A. [The war economy in northern Syria](#), December 2016.

<sup>94</sup> Jebel Saman subdistrict

<sup>95</sup> *Ibid.*

were targeted by US and Russian airstrikes.<sup>96</sup> The agriculture sector, and the market for dairy farm labor, remains viable in Al-Dana, Atareb, Armanaz, Afrin, Salqin, Idleb and Azaz.<sup>97</sup>

One counterexample is the dramatic economic decline of Shaykh Al Hadid subdistrict, located in Afrin district and

bordering Turkey. This is attributed to the high numbers of Kurdish residents, and the poor relations they have with Turkish and Turkish-backed forces, and Turkey’s perceived attempts at removing Kurdish populations from border regions. The Turkish-backed Syrian National Army (SNA) allegedly harasses the significant Kurdish population in the subdistrict, imposes

Humanitarian Indicator	Correlation to 2019 per-capita GDP	Correlation to 2020 real per-capita GDP
% residents in need of health assistance	-0.179**	-0.120
% residents in need of water assistance	-0.254***	-0.167**
% residents in need of food assistance	-0.318***	-0.027
% residents in need of NFI assistance	-0.285***	-0.005
% residents in need of shelter assistance	-0.294***	-0.135*
% residents in need of education assistance	-0.211***	-0.106
% residents in need of livelihoods assistance	-0.053	0.059
% residents in need of security assistance	-0.258***	-0.056
% residents in need of basic needs assistance	-0.153**	0.014

*Table 3: Correlation between the proportion of residents in humanitarian need (subdistrict-level HNAP mobility and needs monitoring data). Statistical significance codes: 0\*\*\*, 0.001\*\*, 0.01\*, 0.05.*

<sup>96</sup> Tokmajyan, A. [The war economy in northern Syria](#), December 2016.

<sup>97</sup> *Ibid.*

arbitrary taxes, appropriates property and randomly arrests citizens.<sup>98,99</sup> This has caused about 80% of the Kurdish population to leave the central town of the subdistrict; they were then replaced by displaced SNA-affiliated families who in turn struggled to replace the economic losses of the outgoing population. Finally, olives were the primary agricultural crop in the area, however much of the crop has been damaged in an attempt to remove livelihood options, and appropriated by smugglers selling cross-border to Turkey.<sup>100,101</sup>

The economic losses incurred by large urban areas were severe, but below the average change in real GDP (-60%) among all subdistricts. The economies of the subdistricts containing Hama and Homs cities have nearly recovered to their pre-conflict level of economic activity. However, the subdistricts containing Aleppo and Idleb cities experienced the greatest economic decline, as expected, especially Idleb's economy, which lost \$371 million in value during the conflict.

The relationship between the subdistrict real GDP per-capita estimates and the percent of residents in humanitarian need were estimated using HNAP's mobility and needs

monitoring dataset.<sup>102</sup> The results are found in Table 3. In 2019, the proportion of people in need was statistically significantly negatively correlated with real per-capita GDP in all assistance categories except livelihoods assistance. However, most of these relationships became weaker and statistically insignificant in 2020, perhaps because the economic hardship caused by the Syrian financial crisis and the COVID-19 pandemic pushed more families into need while the relative prosperity of subdistricts remained constant.

Despite this dramatic change in statistical significance, the negative correlation coefficients confirm the expected relationship; that is, humanitarian need is generally greater in subdistricts with lower real per-capita GDP.

## CITIES

### Night lights as a tool to analyze conflict damage in urban areas

Raw NLRD was used to analyze urban development of Syrian cities during the conflict. Specifically, we map changes in night light reflectance in Aleppo city before, during and after its occupation by ISIS and measure

<sup>98</sup>Syrians for Truth & Justice. [Afrin: Shaykh Al Hadid: Intimidation and Economic Tightening](#). March 2020.

<sup>99</sup> North Press Agency. [Turkish-backed armed groups in Afrin seize 90% of Sheikh-Hadid properties](#). December 2019.

<sup>100</sup> Al-Monitor. [Turkey's 'Olive Branch' takes root in Syrian olive business](#). December 2018.

<sup>101</sup> Syrian Observatory for Human Rights. [Afrin | Turkish-backed military police arrest several civilians in Sheikh Hadid](#). May 2021.

<sup>102</sup> Using the average monthly resident population recorded by HNAP in the mobility and needs monitoring dataset.

changes in night light reflectance between areas occupied by the Syrian government and former opposition forces in Dar'a city. Real GDP was not calculated for cities because it is out of scope for the report; however, a similar estimation procedure can be applied for city-level data.

In conflict contexts, a significant decline in night light reflectance is likely indicative of

electricity cuts due to damage to electrical infrastructure or the destruction of buildings and street lighting. To assess the extent of the latter, we measured the correlation between the proportion of percentage of buildings destroyed in Aleppo as of 2016, acquired from UNOSAT,<sup>103</sup> the 2016 mean night light reflectance, and growth rate in night light reflectance from 2012 to 2016.

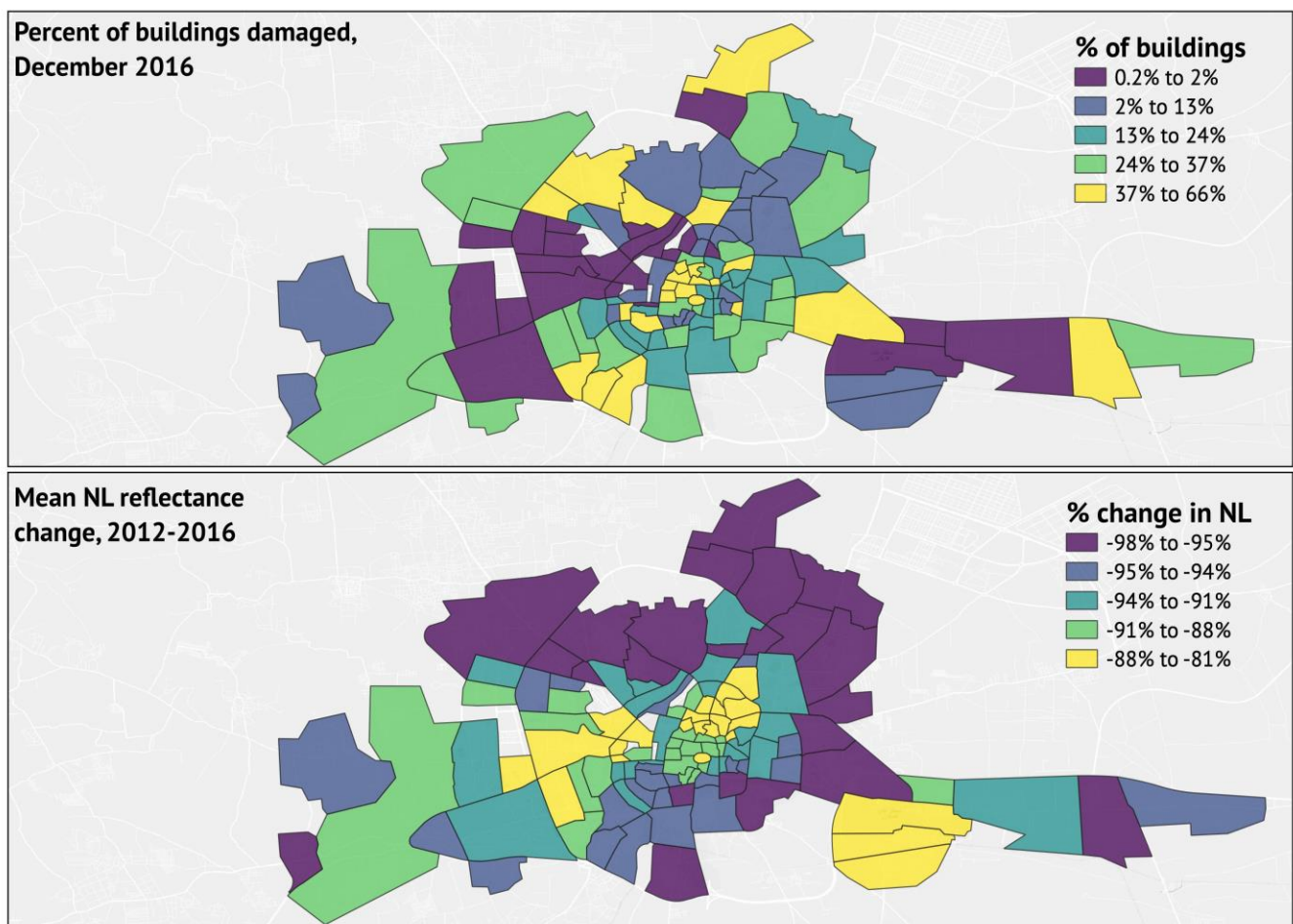
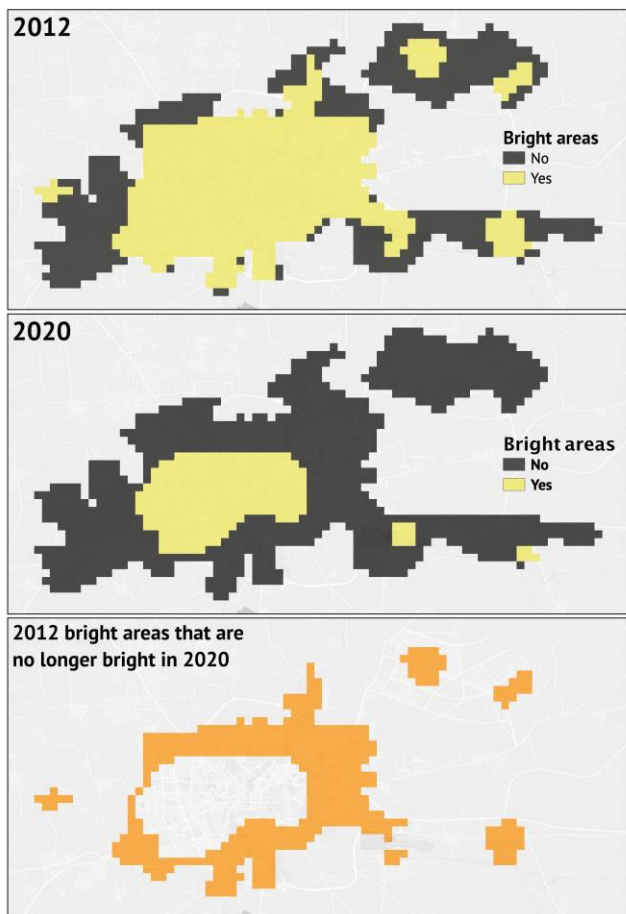


Figure 6: Aleppo city building damage (2016) and the 2012 to 2016 growth rate in night light reflectance. Total night light reflectance in 2016 is only 7.4% of the total reflectance in 2012, but in 2020 total night light reflectance improved to 47% of 2012 total night lights reflectance

<sup>103</sup> OCHA services, HDX, [Percentage of buildings damaged in the city of Aleppo](#)



*Figure 7: Significantly reflective areas in Aleppo city, 2012 and 2016. Notice the outer rim of the city and eastern edge has not regained significant lighting. Also notice the center of Sheik Najjar Industrial City, northeast of Aleppo city, has not regained a significant reflectance level*

Both models were statistically significantly negatively correlated with the proportion of buildings destroyed.<sup>104</sup> A map showing the geographic distribution of these measurements within Aleppo city is found in Figure 6; further, Figure 7 shows where formerly well-lit areas of the city went dark

after the battle of Aleppo. This suggests low and diminished night light reflectance values only directionally indicate the location of residential building damage, and are confounded by the widespread electricity outages caused by damage to electricity infrastructure and street lights: Infrastructure damage impacted electricity output of a much wider area than neighborhoods where buildings incurred heavy damage. Therefore, night light reflectance values and changes in reflectance from a pre-conflict baseline are a decent proxy for building damage, and are likely a better indicator of the extent of electricity provision.

Figure 8 is a time series graph of total night light reflectance in Dar'a city, which we used to compare economic recovery in its northern (Dar'a al-Mahatta) and southern (Dar'a al-Balad) halves of the city, controlled by the Syrian government and opposition groups until July 2018 respectively. Following a reconciliation agreement in the governorate in July 2018, Dar'a al-Balad was placed under the control of former opposition forces.

The trajectory of night light reflectance in Dar'a city accurately demonstrates the relative economic impact of the conflict on the two zones of control in the city, the Syrian government controlling Dar'a al-Mahatta,

<sup>104</sup> Correlation with mean night light reflectance:  $r = -0.19$  ( $p < 0.01$ ); correlation with 2012 to 2016 growth in night light reflectance:  $r = -0.17$  ( $p < 0.05$ ).

and the former opposition controlling Dar'a al-Balad. Dar'a al-Balad was relatively stable between 2013 and 2018, compared to government-held areas that were subject to economic sanctions. This was in part due to job creation by humanitarian aid agencies located in Dar'a al-Balad while outside of government control. More importantly, those jobs were paid in US dollars, which provided stable incomes for many families living in the area. However, economic activity declined in Dar'a al-Balad after it came under government control in 2018.

Specifically, many skilled laborers left Dar'a al-Balad after the Syrian government regained control, which constricted trade through Ramtha and Nasib border crossings and caused businesses to close or reduce in size. Nevertheless, the higher night lights reflectance in Dar'a al-Balad in 2020 is likely the result of the combination of the end of combat operations and the return of residents to the area following reconciliation agreements.

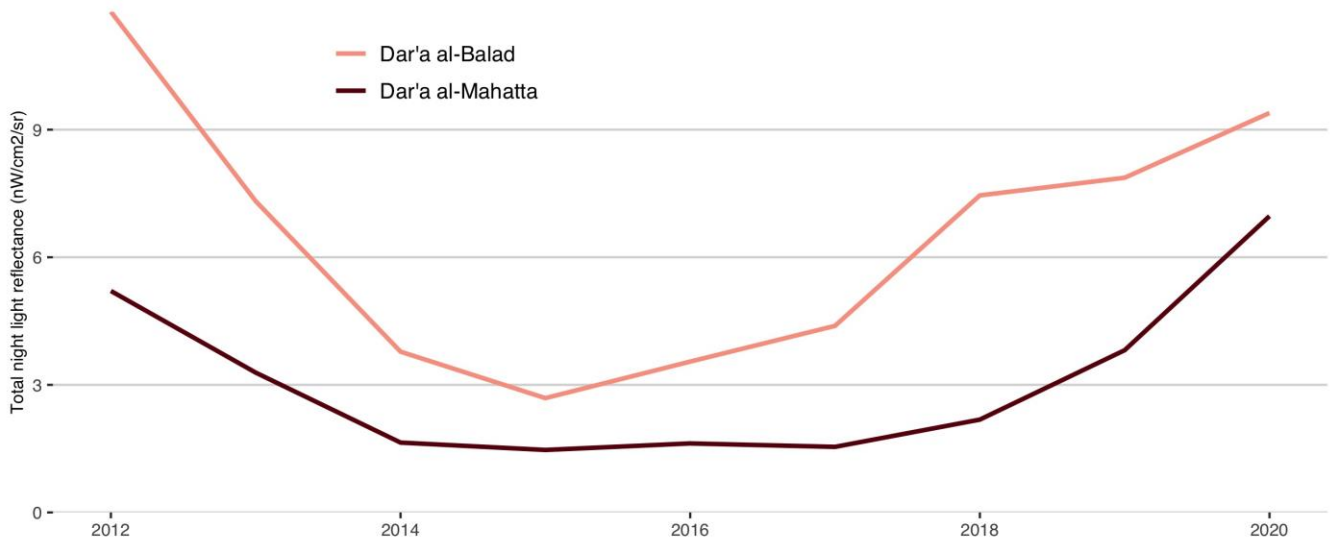


Figure 8: Total night light reflectance in Dar'a al-Balad (former opposition-controlled) and Dar'a al-Mahatta (Syrian government), 2012-2020.

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# CONCLUSION

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National statistics on economic output in Syria are currently produced by international organizations, and regional output statistics have never been collected before or during the conflict. Therefore, our estimates of regional economic output (real GDP) from 2000 to 2020 are novel to economic analyses of Syria and are useful for assessing regional economic trends. Our real GDP disaggregation procedure performed well using the more recent and detailed VIIRS satellite night light images from 2012 to 2020, and adequately using older and less accurate DMSP satellite images. The subdistrict-level estimates appear reliable because they accurately aggregate to higher geographies, follow macro-economic and

conflict-related trends (including urbanization, political violence and occupation), and conform to the known economic geography of Syria. However, values of regional GDP are subject to the national-level statistics being disaggregated, meaning significant national-level overestimations or underestimations will be apparent in regional statistics.

The HAT will share these data upon request with the intention to assist humanitarian program actors in assessing regional economic performance when planning livelihood, resilience, or redevelopment related programming.

# APPENDIX

## Regression results.

	DMSP (national)	DMSP (subdistrict)	VIIRS (national)	VIIRS (subdistrict)
Mean reflectance	-	1.082*** (0.021)	0.445*** (0.067)	0.920*** (0.005)
Median reflectance	0.017 (0.17)	-	-	-
Reflectance std. dev.	1.123*** (0.112)	-	-	-
R-squared	0.91	0.43	0.93	0.94

Table A1: Results of the best-performing regression model for each satellite and geographic aggregation (national or subdistrict). Statistical significance codes: 0\*\*\*, 0.001\*\*, 0.01\*



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The Humanitarian Access Team (HAT) was established in Beirut in March 2015 in response to the collective challenges facing the remote humanitarian response in Syria. Successful humanitarian and development interventions require a nuanced and objective understanding of the human ecosystems in which these interventions occur. To this end, the HAT's most important function is to collect, triangulate, synthesize, analyze and operationalize disparate data and information. Since 2015, HAT analysis has provided a forward-looking template for international interventions in Syria, and facilitated an increasingly nimble, adaptive, integrated, and ultimately impactful international response to the Syrian conflict.

