The environmental impact of infrastructure development:
The case of Dos Bocas Refinery in Mexico

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Abstract

Infrastructure is a double-edged sword, associated with economic benefits and also often with environmental costs. When environmental consequences are not taken into account, infrastructure projects could represent serious threats to the environment. This paper discusses the environmental impact of the construction of the *Dos Bocas* Refinery in Mexico. By using remote sensing techniques, we compared the differences between the NDVI –Normalized Difference Vegetation Index and the EVI – Enhanced Vegetation Index, to assess the extent in which vegetation has decreased in a context of land transformation for infrastructure development in the period between 2019 and 2020. We found that there is a strong decrease of vegetation in the area of interest. We conclude that the EVI provides a better geographical framework of vegetation in our region of interest compared to the NDVI, given its implicit correction parameters for areas where vegetation is relatively high.

Keywords: Dos Bocas refinery, vegetation index, NDVI, EVI, infrastructure.

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1. Introduction

Already under construction in the southern coastal state of Tabasco, the *Dos Bocas* refinery is designed to be the most important energy infrastructure project in Mexico. The new refinery would produce 170,000 barrels per day (b/d) of gasoline and 120,000 b/d of ultralow-sulfur diesel[1], which will help to increase Mexico's gasoline production and ensure the demand of the world's 6th largest fuel market, similar in size to the markets of Spain, Colombia, Peru, Portugal and Ecuador put together[2].

In early April 2019, several Mexican organizations considered that the *Dos Bocas* Refinery was an ill-conceived project for two reasons: 1) it wasn't economically viable, a budget of $8 billion will be insufficient to build it, and 2) its construction would involve high environmental risks[3]. Regardless of these concerns, *Petroleos Mexicanos* (PEMEX) started its construction in August 2019. This paper evaluates the environmental impact of the refinery during the initial phase of construction by analyzing the changes in the extent of live vegetation in the area of the refinery.

Remote sensing provides a novel approach to analyze vegetation change. This paper focuses on the comparison of two vegetation indices to analyze the *Dos Bocas* refinery environmental impact: the NDVI –Normalized Difference Vegetation Index and EVI – Enhanced Vegetation Index. Given that both indices are widely used, the development of the refinery offers an interesting case to evaluate their performance in terms of mapping vegetation change, focusing on which one provides a better fit.

The paper is organized as follows. Section 2 explains briefly the literature of infrastructure and environmental impact. Section 3 discusses the project of the *Dos Bocas* refinery and its environmental impact. Section 4 analyses the evolution of vegetation under the construction area of the refinery by using remote sensing tools. Section 5 concludes the paper.

2. Infrastructure and environmental damage: A literature review

Infrastructure is the foundation in which developed economies are built up. Policy makers assume that infrastructure fosters economic growth. The direct effect is raising the productivity of production factors[4]. For example, businesses can lower fixed costs of production. Households can have access to more competitive prices as the goods and services they consumed are provided through infrastructure services. Furthermore, infrastructure projects, such as roads, electrification and clean water development are integral parts of development and poverty alleviation.

[1] Dos Bocas Refinery, https://dosbocas.energia.gob.mx/.
[2] Forbes, "New Fuel Retailers Eye PEMEX Market", https://www.forbes.com/sites/thebakersinstitute/2017/12/14/new-fuel-retailers-eye-pemex-market/#3d5d7db6c2dd.
[3] The New York Times, "An $8 Billion Refinery? Mexican President Says, Yes We Can", https://www.nytimes.com/2019/05/09/world/americas/mexico-refinery-pemex.html.
[4] Brooking, "Is infrastructure investment the answer to sluggish economic growth?", https://www.brookings.edu/blog/future-development/2016/04/05/is-infrastructure-investment-the-answer-to-sluggish-economic-growth/.

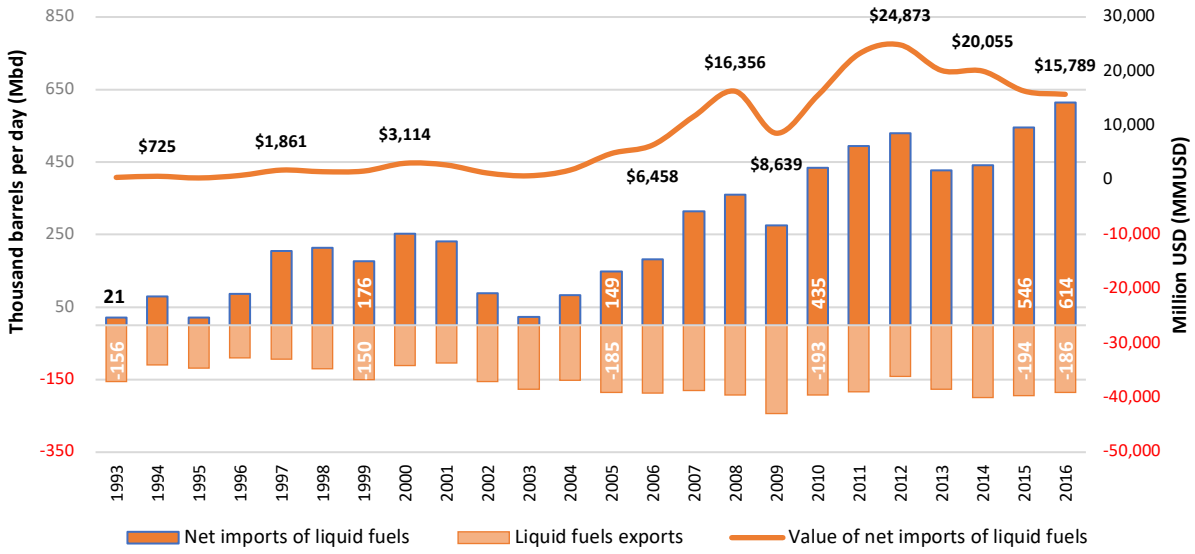
Infrastructure is a double-edged sword, associated with economic benefits and also often with environmental costs. When environmental consequences are not taken into account, infrastructure projects could represent serious threats to the environment, such as habitat fragmentation, poaching and degradation of the ecosystem[5]. Although infrastructure can provide important socioeconomic benefits, governments generally ignore these risks to local environment, which have implications for quality of life and climate change.

Decisions on the location, type, and timing of infrastructure developments can have profound implications for the environment[6]. Governments should integrate environmental considerations in the cost-benefit analyses they use to evaluate new projects and also promote regulations to manage its environmental impacts and mitigated their risk.

3. Why a new refinery? *Dos Bocas*: A general overview and its environmental impact

Mexico is a net importer of petroleum products. There has been an increasing dependency of refined products from U.S. because of two trends: 1) an increasing Mexican demand for American oil products, and 2) a declining motor fuels refining output in Mexico. From 1993 to 2016, net imports of petroleum products went from 20.7 to 613.9 thousand barrels per day (Mbd), equivalent to an average growth rate of 15.8%. In the last 10 years, the demand for liquid fuels increased at a rate of 1.4% per year. However, domestic output decreased at a rate of -4.1% per year during the same period.

Graph 1: Mexico, volume and value of liquid fuels



Source: SENER – SIE.

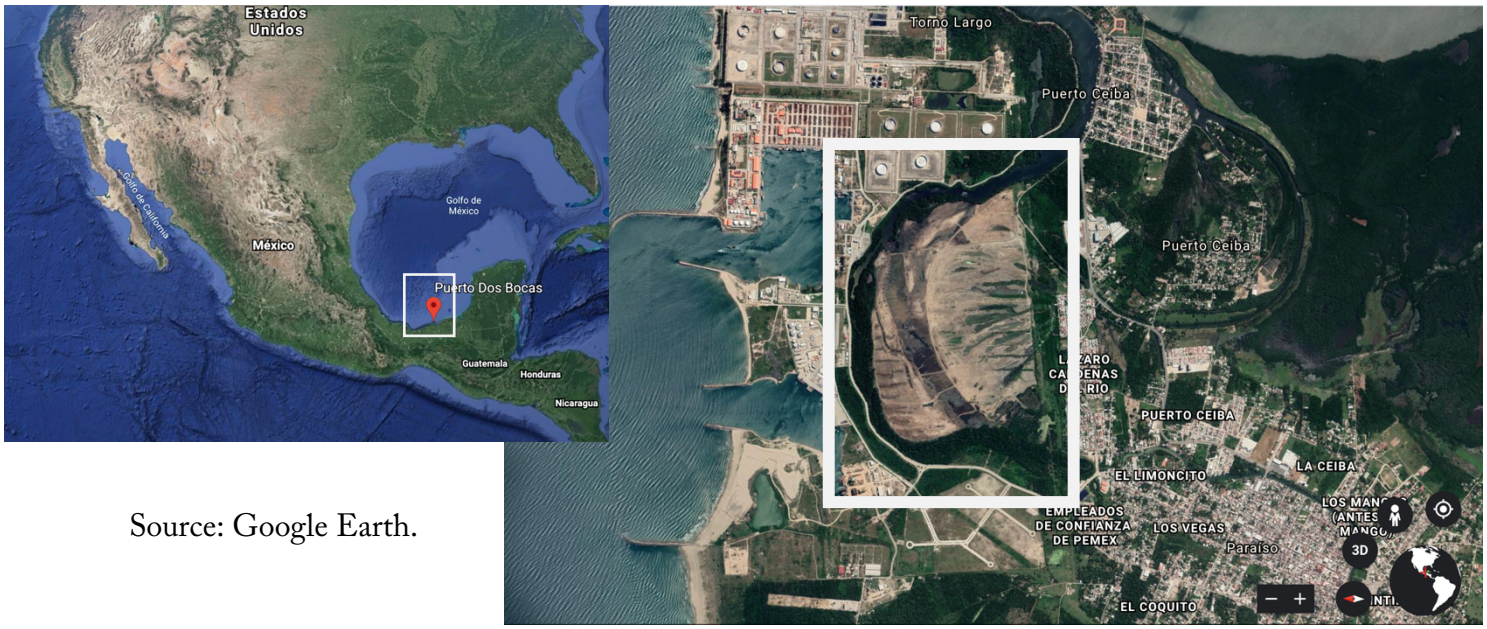
[5] Laurance et al. 2015, 259-260.
[6] OECD, "OECD Reference Note on Environmental and Social Considerations in Quality Infrastructure", https://www.mof.go.jp/english/international_policy/convention/g20/annex6_4.pdf.

The construction of the Dos Bocas refinery addresses this concern. Energy sovereignty has been stated as the main goal of AMLO's energy agenda. AMLO has stated that Mexico should increase its domestic production in order to reduce its dependency to U.S. imports in natural gas and oil products.

One the main concerns of the refinery project was its environmental impact: its threat to surrounding flora and fauna. Its development would imply cutting down protect mangrove trees on the site to clear the land for the construction. Mexico has the fourth-largest area of mangroves in the world and the country committed to their protection under the Paris Agreement[7]. Mangroves have an important function regarding carbon capture: they capture up to five times more than inland flora and help to protect the region against flooding caused by climate change[8]. The rate of deforestation is high in Mexico: according to the University of California, San Diego, Mexico could lose half its mangrove population in the next 50 years. Costs are not just environmental but economical as well: this kind of trees create complex ecosystems that provides close to 6% of Mexico's GDP[9].

Since August 2019, mangroves and other vegetation located in *Dos Bocas* have been cut down to provide vehicle access to the construction area. In fact, Image 1 shows a landscape razed in the refinery's location. Mexico's environmental regulator ASEA issued a construction permit, therefore these actions are legal under the current regulatory framework.

Image 1: *Dos Bocas* refinery's location



Source: Google Earth.

[7] Quartz, "Mexico is illegally destroying protected mangrove trees to build an $8 billion oil refinery", https://qz.com/1807407/mexico-is-illegally-destroying-mangroves-to-build-lopez-obradors-oil-refinery/.
[8] Ibid.
[9] Ibid.

4. Environmental impact of the *Dos Bocas* refinery

Vegetation loss is the most visible negative impact of the refinery. This section provides an analysis of the vegetation evolution in the refinery area. First, I explain the methodology and the resources I used in my analysis. Second, I provide the spatial and temporal changes in the extent and distribution of vegetation using the NDVI index in the municipality of Paraíso, the construction area of the refinery. Third, I compare my results using the EVI index for robustness purposes.

Methodology

Satellite datasets have been utilized to monitor the changes in vegetation coverage. Landsat series images (Landsat 5, 7 & 8) have high temporal resolution (16 days[10]) and spatial resolution (30 meters[11]), also with high imaging quality, currently covering the widest range of time (1984-present). In particular, I used the package Landsat 8 Collection 1 Tier 1 Raw Scenes from the U.S. Geological Survey (USGS). All Collection 1 data share common radiometric and geometric parameters. The USGS recommends using Tier 1 data for time-series analysis since it has the highest radiometric, less cloud cover, and better positional quality. Furthermore, it has better precision terrain processing and have been inter-calibrated across the Landsat sensors[12].

My analysis starts in 2019, year in which the construction of the refinery began. Therefore, after importing data from the satellite, I filtered the image collections for the first two months of 2019 and 2020. I chose this period of time for two reasons: 1) availability of data for 2020 and 2) standardization of the comparison period. I decided to focus attention on changes in vegetation cover and to do so, the near-infrared band must be used given the fact that chlorophyll in vegetation reflects this wavelength. Therefore, I selected the band combinations[13] of 5-4-3. Additionally, I implemented a reducer as a way to composite images and account for possible cloudiness.

I used the Normalized Difference Vegetation Index (NDVI) to estimate changes in vegetation by plotting in levels of yellow and green to have a continuous representation of the index found. Finally, after conducting major analysis and image classification on Google Earth Engine, I export rasters to ArcGIS, where we reclassified output rasters to focus on vegetation only.

NDVI analysis

The NDVI is the most used vegetation index in remote sensing since its introduction in 1970. The NDVI quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). The NDVI index ranges from -1 to 1[14].

[10] Landsat 8 visits the same spot on the Earth every 16 days. That means that over a 6 month period, there will be approximately 12 images.
[11] Each Landsat pixel covers a 30 by 30-meter area.
[12] Yale University, "Landsat Collections", https://yceo.yale.edu/landsat-collections.
[13] Landsat 8 has 11 bands.
[14] Drisya *et al.* 2018, 12.

Positive NDVI values –greener areas– are associated with vegetated areas, while zero and negative values –darker colors– correspond to water bodies and bare soil.

The NDVI index is calculated by the following formula:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

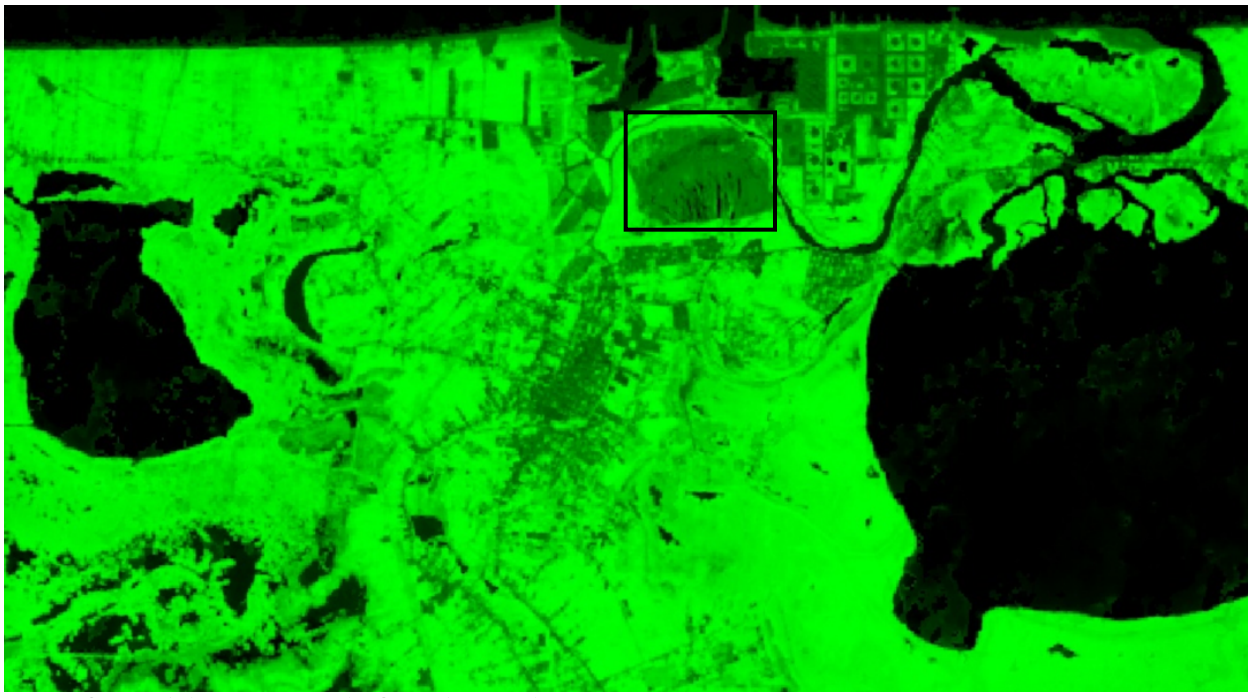
where NIR is the reflectance value of the near-infrared band, and RED is the reflectance of the red band. In Landsat 8, the NIR is represented by band 5, while RED is band 4.

By using the image collection from the USGS Landsat 8 Collection 1 Tier 1 Raw Scenes, I created a simple cloud-free Landsat composites using GEE's default parameters. Then, the NDVI was calculated with the function above using the cloud-free Landsat image. The palette was adjusted to provide a better visualization: to black (lowest value) and green (highest value). Images 2 and 3 show the spatial distribution of vegetation using the NDVI index for Paraíso, Tabasco. At first sight, we see that there has been a decreasing in vegetation from 2019 to 2020. In 2020, the refinery area of construction has a darker color.

Reclassifications were employed to identify diminished vegetation cover between 2019 and 2020. According to USGS remote Sensing phenology[15], an area with NDVI value from 0.1 to -1 is a non-vegetation area (e.g. rock, sand, snow), while an area with dense vegetation canopy usually has values from 0.3 to 0.8. Therefore, I define -0.3 (or less) as the threshold for diminishing vegetation area.

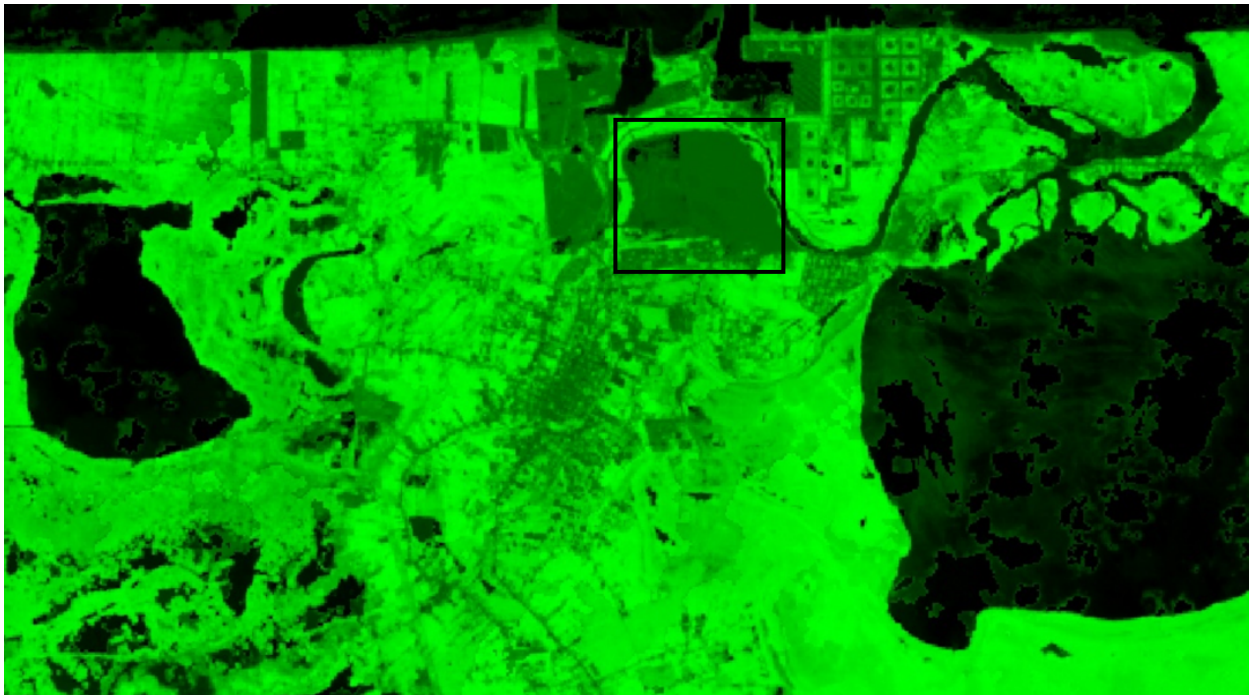
[15] "Landsat Surface Reflectance-Derived Spectral Indices." Landsat Normalized Difference Vegetation Index, United States Geological Survey.

Image 2: Spatial distribution of vegetation, Paraíso, Tabasco for the year 2019



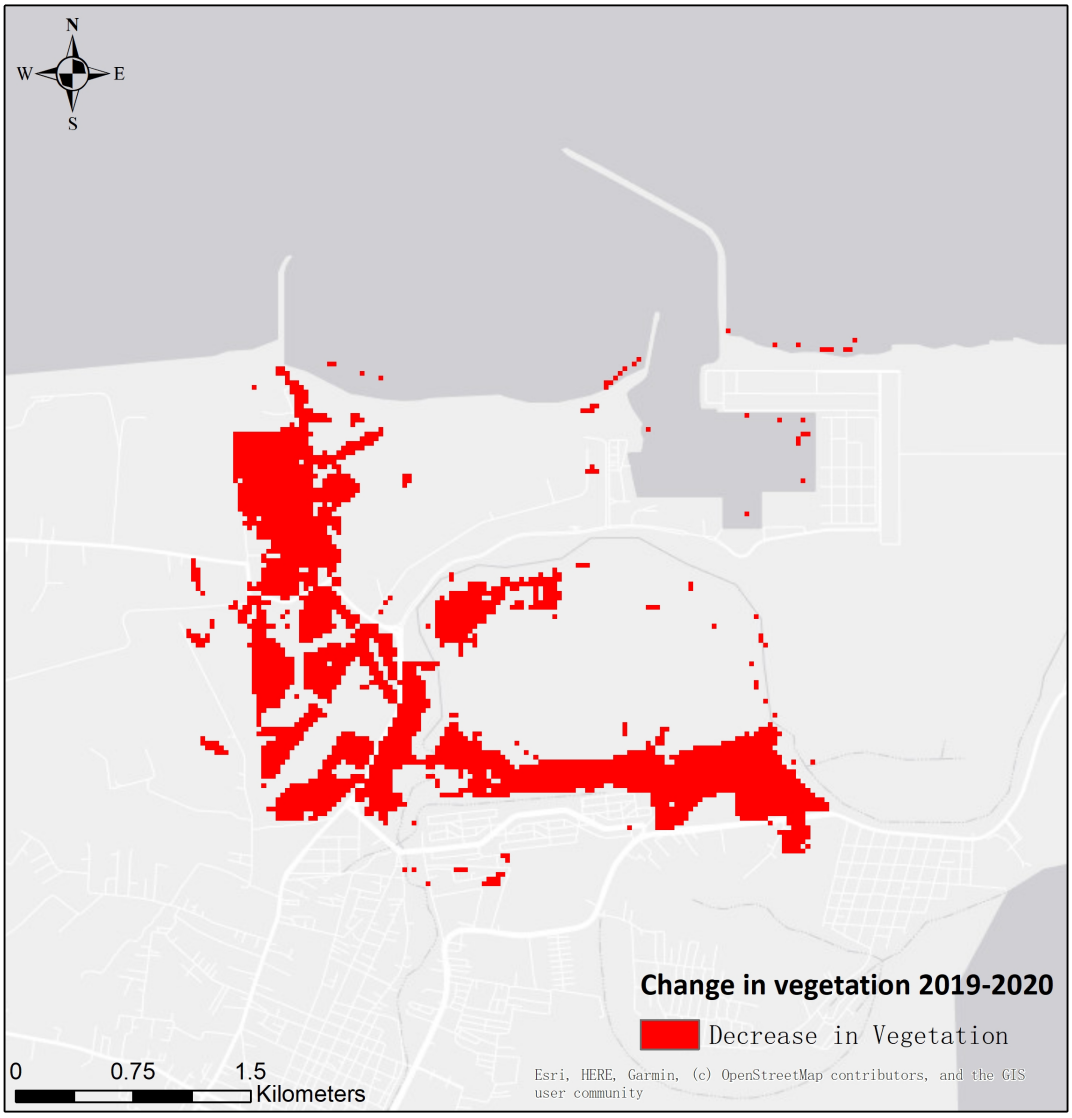
Source: Own elaboration with Google Earth Engine.
Note: The image is made considering the data of January and February of 2019.

Image 3: Spatial distribution of vegetation, Paraíso, Tabasco for the year 2020



Source: Own elaboration with Google Earth Engine.
Note: The image is made considering the data of January and February of 2020.

Image 4: Change in Vegetation in the period 2019 to 2020, Paraíso- Tabasco. NDVI



Elaborated on March 17, 2020. Source: Own elaboration with data from the U.S. Geological Survey.

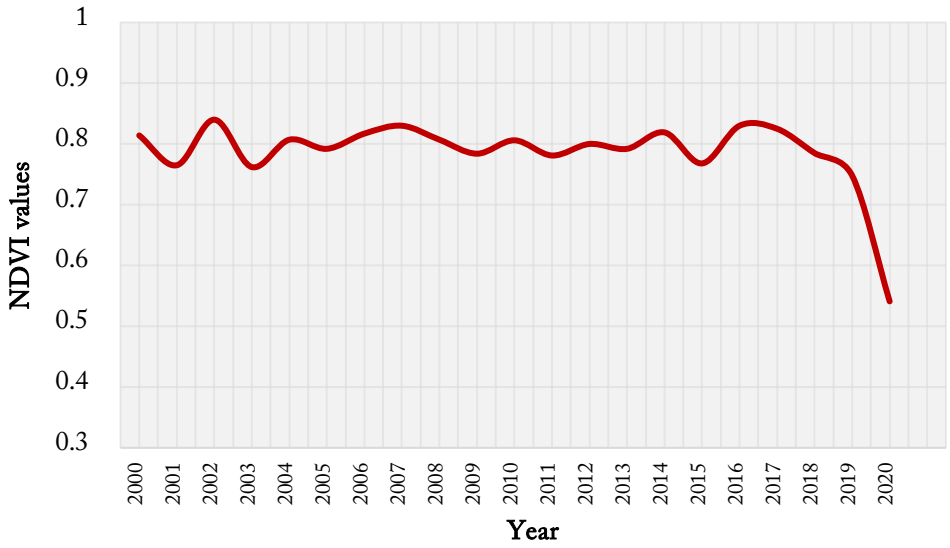
Source: Own elaboration with Google Earth Engine for the months of January and February.

Image 4 shows that, in the period between 2019 and 2020, the municipality of Paraíso experienced changes in vegetation cover as a result of the project. Decreases –in red, are located closed to the construction area of the refinery. Vegetation degradation has increased most likely to make ways for roads and associated infrastructure for the operation of the refinery. In sum, despite of being a protected zone and committed to it under the Paris Agreement, the data shows that the development of the refinery is threating these zones.

So far, we know that vegetation is decreasing in this area due to the refinery. But, in what extent? A second step of the analysis is to measure the magnitude of the deforestation. For that purpose, I analyzed the NDVI time series by examining the linear trends in the last 20 years. Graph 2 shows a stable trend in the NDVI in the period between 2000 and 2020. Furthermore, it shows that, on average, the region of interest is an area with dense vegetation canopy –usually has values from

0.3 to 0.8. The largest loss in vegetation cover is recorded from 2019 to 2020: the NDVI decreased by 28%. Certainly, an outcome due to the construction of the *Dos Bocas* refinery.

Graph 2: NDVI values, 2000-2020



Source: Own elaboration with Google Earth Engine.

EVI analysis

Every index has its limitations. NDVI is sensitive to the effects of soil and atmosphere, therefore, I propose another index to compare my findings using the NDVI. If better, the new index will provide a more accurate analysis of vegetation. I suggest an analysis with the Enhanced Vegetation Index (EVI).

The state of Tabasco has high vegetation levels. The EVI improves on NDVI's spatial resolution since it's more sensitive to differences in heavily vegetated areas. In fact, EVI is an index that incorporates both background adjustment and atmospheric resistance concept[16], a disadvantage of the NDVI.

According to the work of Liu and Huete (1995), the EVI is defined as:

$$EVI = G * \frac{NIR - RED}{NIR + (C1 * RED - C2 * BLUE) + L}$$

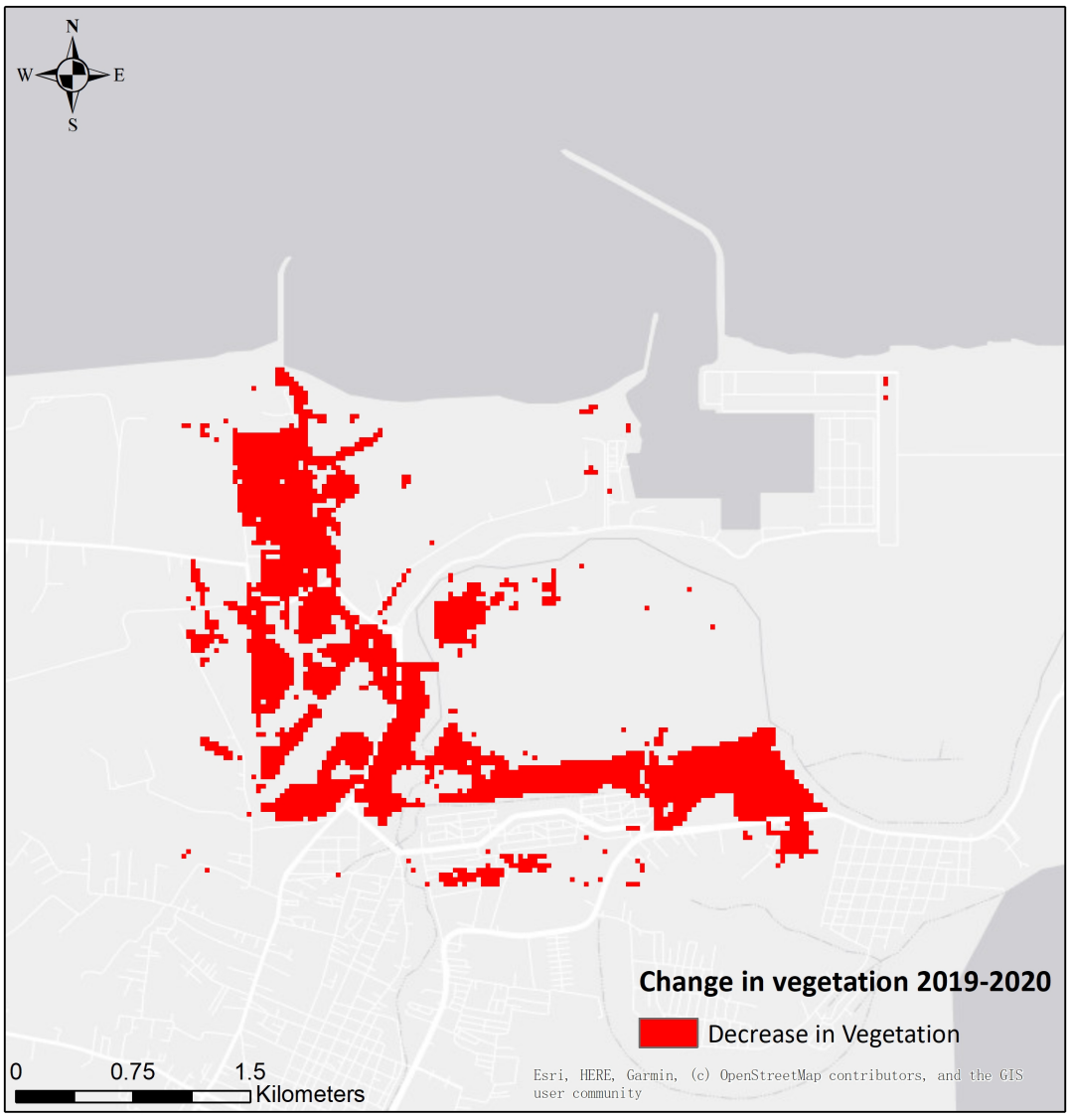
where L is a soil adjustment factor, and C1 and C2 are coefficients used to correct aerosol scattering in the red band by the use of the blue band. The NIR is the reflectance value of the near-infrared band, RED is the reflectance of the red band and BLUE, the blue band. In

[16] Matsushita et al. 2007, 2637.

general, G=2.5, C1=6.0, C2=7.5, and L=1. In Landsat 8, the NIR is represented by band 5, RED is band 4, and BLUE is band 2.

I apply the same methodology I explained to analyze the vegetation coverage using the NDVI index. I apply the function above using a cloud-free Landsat image to calculate the EVI Index. Image 5 shows the EVI Index in Tabasco. The results didn't change: the project is creating vegetation degradation. However, EVI might be a better index to reflect high density vegetation areas (as shown in Graph 2). EVI provides a better geographical framework of vegetation in our region of interest compared to the NDVI, given its implicit correction parameters for areas where vegetation is relatively high.

Image 5: Change in Vegetation in the period 2019 to 2020, Paraíso- Tabasco. EVI



Elaborated on March 17, 2020. Source: Own elaboration with data from the U.S. Geological Survey.

Source: Own elaboration with Google Earth Engine for the months of January and February.

5. Discussion

The Mexican administration should pay attention to the environmental impact that the Dos Bocas refinery is creating in the Paraíso's ecosystem. While it's true the refinery might reduce Mexico's dependency from U.S. imports, it's a fact the environmental damage is creating by its development. Mexico's environmental regulator ASEA should consider in revising the permits it issued and also promote more active monitoring in the construction site.

It's not clear that the benefits of this project are going to be greater than the costs. First, it will be difficult to increase gasoline production if Mexico doesn't have the raw material to produce it, crude oil. Second, if the six existing refineries don't improve their efficiency, it's difficult that Mexico would reduce its fuel imports that have come mainly from U.S. Dos Bocas refinery won't be enough. Therefore, the economic benefit of the PEMEX refinery is questionable.

Estimating monetary value of an ecosystem is challenging. However, according the Mongabay, mangroves –the ecosystem at risk with the refinery– provide an annual benefit of $194,000 per hectare[17]. There's evidence that has shown than mangrove forests act a long-term carbon sink: up to 122 million tons of carbon were released due to mangrove forest loss in the last 20 years[18].

Independent research on this topic should be encouraged. In 2008, the Mexican Institute of Petroleum cited the potential environmental damage of this project[19], since then, little investigation has done. This paper contributes to provide evidence of the environmental impact of its construction with the goal to increase awareness of the problem and promote regulations to alleviate it.

6. Conclusions

With the construction of the refinery, the status of vegetation degradation is obvious. Based on the analysis of NDVI, I found an increasing decline in green areas to, most likely, make ways for roads and associated infrastructure for the operation of the refinery. To further visualize the vegetation in the region of interest, I applied the EVI Index to detect the high-density vegetation changes, which adjust the results into a high resolution. Findings didn't change. The Mexican government should pay more attention to the relationship between diminished vegetation coverage and development of new infrastructure.

Further research should address the other negative impacts of *Dos Bocas* refinery. Although ASEA gave a permit to initiate the construction of the refinery, it also raised concerns over impacts on air quality and other threats to surrounding flora and fauna in the region. Overall, these analyses will contribute to have a broader picture of the net benefit of this key energy project.

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[17] Mongabay, "New study finds mangroves may store way more carbon than we thought", https://news.mongabay.com/2018/05/new-study-finds-mangroves-may-store-way-more-carbon-than-we-thought/.
[18] Ibid.
[19] BnAmericas, "Concerns surge after Dos Bocas environmental approval", https://www.bnamericas.com/en/news/concerns-surge-after-dos-bocas-environmental-approval.

References

BnAmericas (2019). Concerns surge after Dos Bocas environmental aproval. https://www.bnamericas.com/en/news/concerns-surge-after-dos-bocas-environmental-approval. Accessed on March 14, 2020.

Brooking (2016). Is infrastructure investment the answer to sluggish economic growth? https://www.brookings.edu/blog/future-development/2016/04/05/is-infrastructure-investment-the-answer-to-sluggish-economic-growth/. Accessed on March 14, 2020.

Drisya, J., & Roshni, T. (2018). Spatiotemporal Variability of Soil Moisture and Drought Estimation Using a Distributed Hydrological Model. In Integrating Disaster Science and Management (pp. 451-460). Elsevier.

Forbes (2017). New Fuel Retailers Eye PEMEX Market. https://www.forbes.com/sites/thebakersinstitute/2017/12/14/new-fuel-retailers-eye-pemex-market/#3d5d7db6c2dd. Accessed on March 14, 2020.

Laurance, W. F., Peletier-Jellema, A., Geenen, B., Koster, H., Verweij, P., Van Dijck, P., ... & Van Kuijk, M. (2015). Reducing the global environmental impacts of rapid infrastructure expansion. Current Biology, 25(7), R259-R262.

Liu, H. Q., & Huete, A. (1995). A feedback based modification of the NDVI to minimize canopy background and atmospheric noise. IEEE transactions on Geoscience and Remote Sensing, 33(2), 457-465.

Matsushita, B., Yang, W., Chen, J., Onda, Y., & Qiu, G. (2007). Sensitivity of the enhanced vegetation index (EVI) and normalized difference vegetation index (NDVI) to topographic effects: a case study in high-density cypress forest. Sensors, 7(11), 2636-2651.

Ministry of Energy, Mexico (2020). Dos Bocas Refinery. https://dosbocas.energia.gob.mx/. Accessed on March 14, 2020.

Mongabay (2018). New study finds mangroves may store way more carbon than we thought. https://news.mongabay.com/2018/05/new-study-finds-mangroves-may-store-way-more-carbon-than-we-thought/. Accessed on March 14, 2020.

Murtaza, S., Kang, K., & Tokuoka, K. (2007). The Nexus Between Infrastructure and Environment. Evaluation Cooperation Group of the International Financial Institutions. Evaluation Brief, 5.

OECD (2019). OECD Reference Note on Environmental and Social Considerations in Quality Infrastructure. https://www.mof.go.jp/english/international_policy/convention/g20/annex6_4.pdf. Accessed on March 14, 2020.

Quartz (2020). Mexico is illegally destroying protected mangrove trees to build an $8 billion oil refinery. https://qz.com/1807407/mexico-is-illegally-destroying-mangroves-to-build-lopez-obradors-oil-refinery/. Accessed on March 14, 2020.

The New York Times (2019). An $8 Billion Refinery? Mexican President Says, Yes We Can. https://www.nytimes.com/2019/05/09/world/americas/mexico-refinery-pemex.html. Accessed on March 14, 2020.

Xue, J., & Su, B. (2017). Significant remote sensing vegetation indexes: A review of developments and applications. Journal of Sensors, 2017.

Yale University (2020) Landsat Collections. https://yceo.yale.edu/landsat-collections. Center for Earth Observation. Accessed on March 14, 2020.