The Impact of Image Resolution on Remote Sensing of Energy Infrastructure

The Issue

The United Nations' seventh Sustainable Development Goal (SDG) advances the provision of affordable and clean energy for all. Electricity grids are a vital component of this vision. The world's electricity grids, are in need of significant planning, expansion and refurbishment to cope with the zero- or low-carbon energy systems of the future. Reliable and up-to-date data on the location of grid infrastructure, such as transmission towers, is the basis that policymakers and other stakeholders need in order to create the (political) roadmap for achieving SDG 7. However, data acquisition is a highly cost-intensive, slow, and hard-to-scale exercise. Existing research using remote sensing focuses on the use of ultra high-resolution imagery, leaving a gap in knowledge regarding the impact of image resolution on power grid tower detection.

Our Approach

We use satellite and drone imagery from 5 different countries artificially lower their resolution (Fig. 1). Then state-of-the-art object detection models based on a Mask-RCNN architecture from the *Detectron2* model zoo are fine-tuned on the individual sets of image resolution. To evaluate our models, we use the Mean Average Precision (MAP) at the 0.5 threshold. Our overall metric is, hence, called AP50. In subsequent experiments we investigate (1) the effect of image resolution on the models' performance, (2) the ability to generalise in across biotopes, and (3) the effect of tower sizes on model performance.

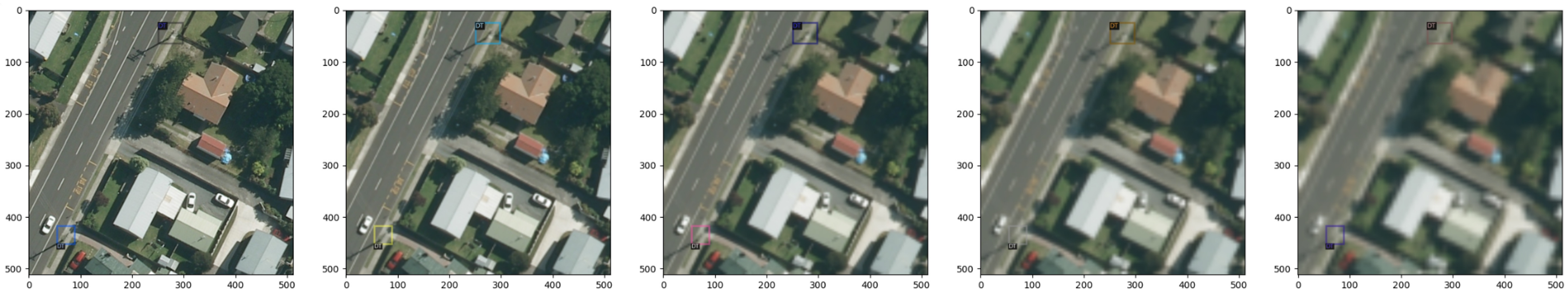

Fig. 1: Visualization of the downsampling process for an example image including the ground truth bounding boxes.. The original image with resolution 15 cm/pixel is downsampled to 30 cm/pixel, 50 cm/pixel and 100 cm/pixel (left to right).

Experiment 1

First, we study the ability of location-generic models and understand their sensitivity to decreasing spatial resolution. We find that the task of electricity tower detection is too context-dependent, to aim for one detection model that is able to generalize across locations. Further, the results are not conclusive enough to set a definitive threshold below which object detection of electricity infrastructure is no longer possible.

Experiment 2

Next, we simulate a situation in which there is no training data available for a location of interest to examine a potential use case for data-sharing between regions. We find that it is crucial to train the model with data from the respective location of interest and that when such data is not available the low model performance can be slightly improved when using data of locations with a similar geography.

Experiment 3

Finally, based on the existing knowledge about the impact of object size on detectability, we investigate the impact of tower size on detection performance. We find that, independent of resolution, detection capability for larger towers is higher than for smaller towers. Crucially, we observe that the model can detect large towers even in imagery with resolutions so low that distribution towers are invisible to the human eye (2-3 m/pixel).

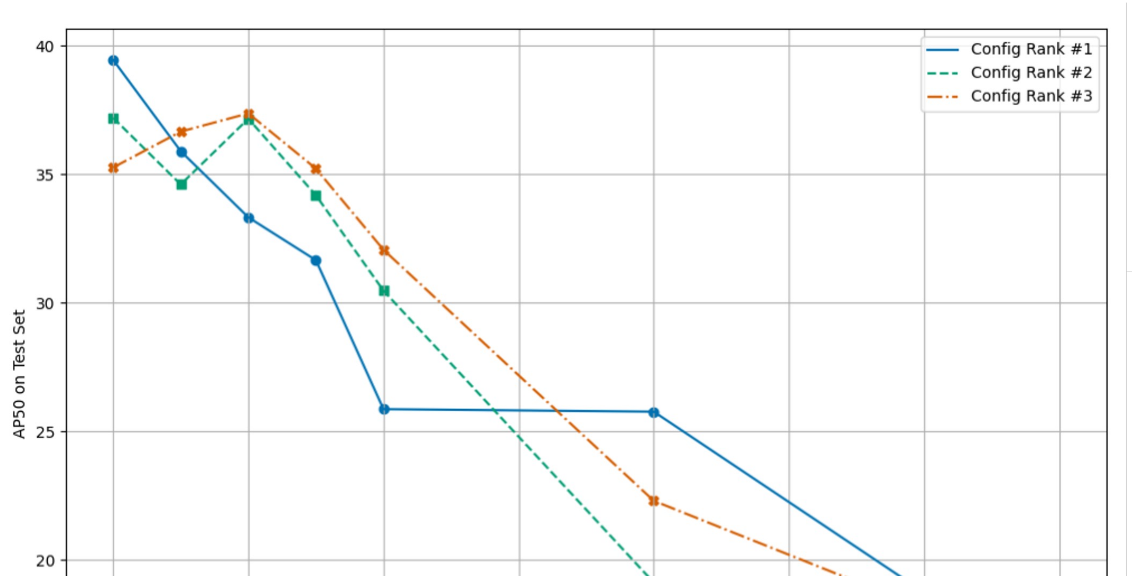

Fig. 2: Effect of resolution on detection performance. AP50 scores for all three configurations on the test set for decreasing resolutions.

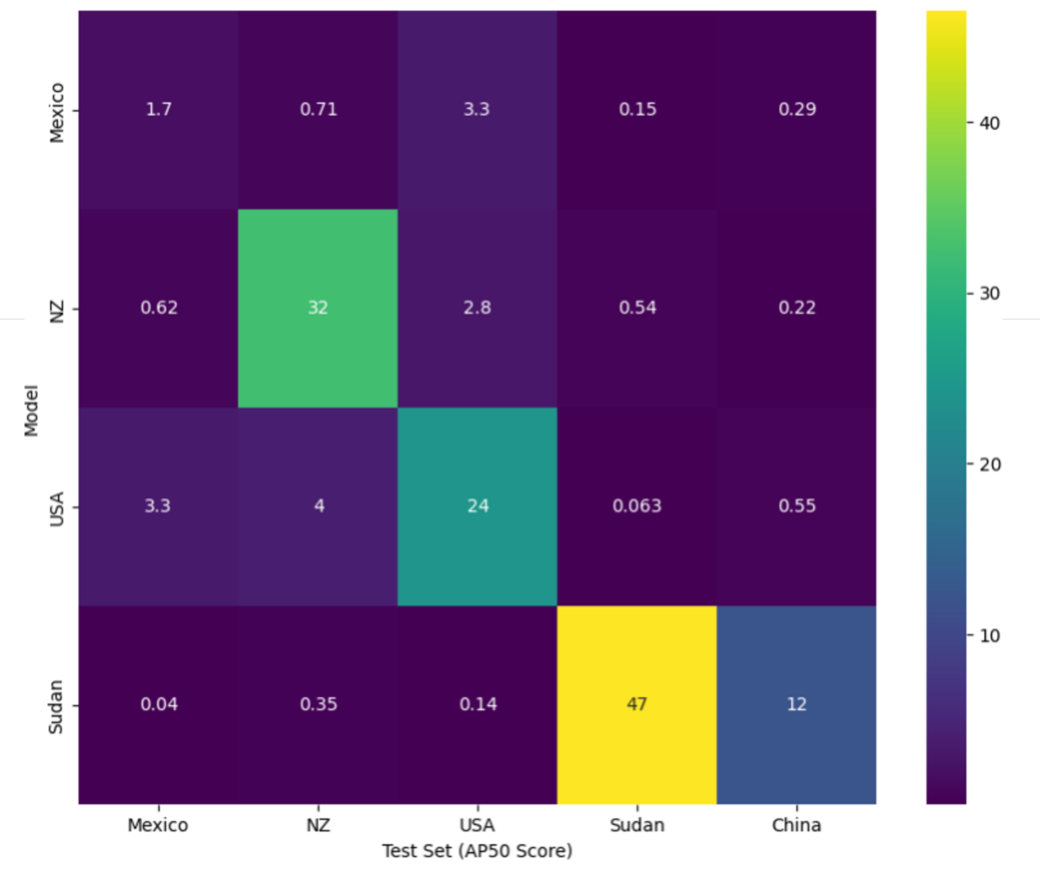

Fig. 3: Model performance stratified by country. The diagonal shows the performance on the in-sample test set and each row shows the performance of a model on the other countries.

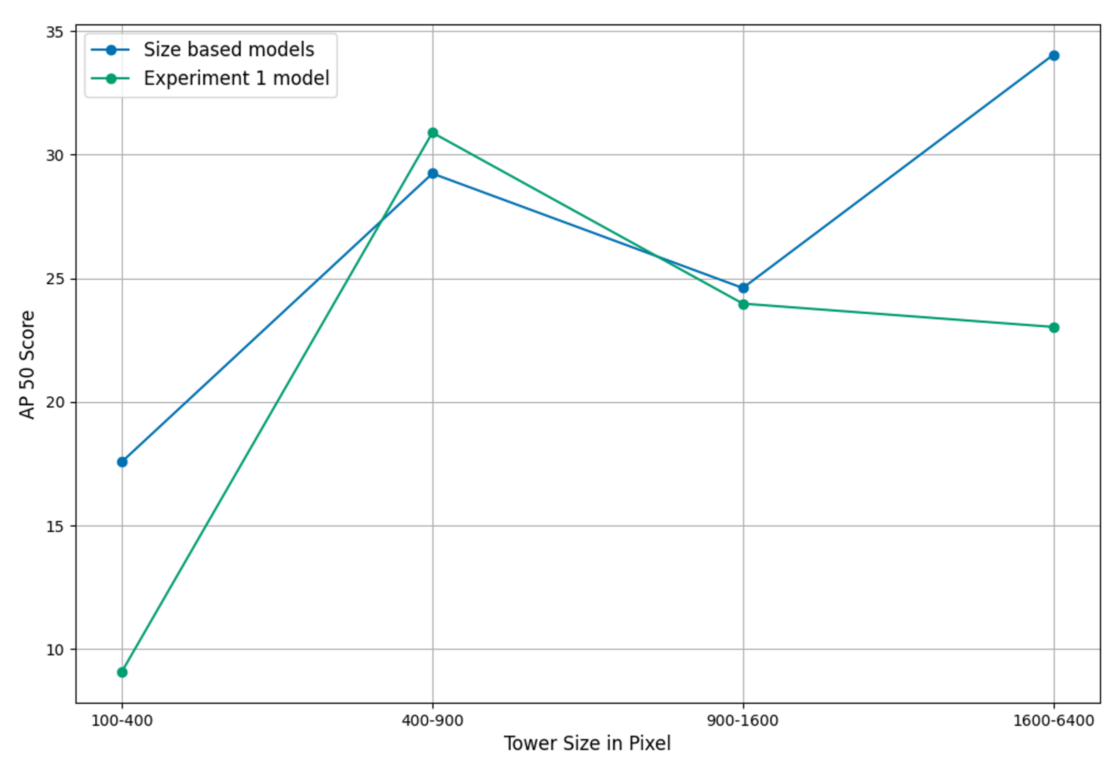

Fig. 4: Model Performance on the test set for different tower sizes, holding resolution constant at 30 cm/pixel. Note: The size-based models are multiple models each specifically trained for detecting a specific tower size, whereas the Experiment 1 model is only a single model tested on the individual tower sizes.

Conclusion

We find that electricity tower detection on a large scale is only possible with commercial satellite imagery. Further, we demonstrate that the detection performance of the model is highly sensitive to tower size, locational characteristics such as ground colour, and the distribution of these features in the training data used. We suggest to first identify regions with similar characteristics, such as topography, geographical environment, and energy infrastructure. Policy makers and modellers from similar regions could share high-resolution data and labelling to be utilised for the continuous development of more refined models while saving resources that can be invested in generally obtaining the highest-resolution images possible. Our research on tower detection should be expanded with experiments on grid detection. By predicting grid lines using path detection models, the inherent nature of electricity grids can be utilised to filter out false positives and minimise the effect of non-detection. The ability of such an algorithm to draw a correct grid based on the detection predictions of the detection model could be a valid and practice-oriented metric to define a resolution threshold for the detection model.

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