Understanding the Land Use and Water Systems of the Mekong River

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***Abstract* - The Mekong River region's long-term social and economic sustainability is being threatened by the growing development of hydropower and its impacts on the river, surrounding populations, and vital industries. In this study we have analyzed these unintended impacts through data analysis in hopes of quantifying trends associated with the rapid hydropower development. It is important to consider the human and social dimensions of hydropower in the area as the dams' effects trickle down to the natives of the Mekong Region, the river itself, and all other life dependent on it. We conducted our research by utilizing data sets and surveys released by certain organizations such as the FAO (Food and Agriculture Organization), the WB (World Bank), and CGIAR (Consultative Group for Agricultural Research) International to develop a basis for drawing conclusions.**

In this study, we segment the analysis into five sectors: hydropower, agriculture, fisheries and aquaculture, economy, and land use. We then correlate dam implementation and hydroelectric capacity with impacts to the Mekong River Basin. Through our research, we expect to find quantifiable correlations between the increased development of hydropower and the resulting impacts on the Mekong's inhabitants and the region's overall well-being.

INTRODUCTION

The industrial growth in the Lower Mekong Region (Cambodia, Laos, Myanmar, Thailand, Vietnam) is being developed to produce more resources and promote further economic growth [1]. Since the early 1960's, the production of hydropower has been a crucial factor for urbanization and economic growth [2]. However, before any of the existing land use drivers took hold, the Mekong River and those inhabitants around it were part of a mutually beneficial relationship [1]. The lack of industrialization allowed the river to flow in a natural manner. However, there is now a crossroads between tapping further into the potential it provides and conservation of life [1]. The World Wildlife Fund (WWF), one of the world's largest non-profit environmental conservation organizations, noted that the Mekong Region is "currently facing a defining point in its history where proposed developments and imminent environmental changes will directly impact economic performance for decades to come" [1]**.** Further than simply economic performance, our group needed to take into account many other industries native to the region for a holistic product [4]. Each of these aspects encapsulates the ongoing situation as a product of hydropower development as well as provides a unique angle to understanding the network as a whole.

Figure 1: Map of Lower Mekong River Basin [2]

DATA

1.1 Data Collection

Data collection was subdivided based on the data requirements of each sector of interest. To create a dataset which contained each dam and its attributes, necessary data sources included regional dam records from CGIAR and individual state department energy reports. All agricultural, land-use, and economic data was obtained from The UN Food and Agriculture Organization's FAOSTAT engine. Fishery data was obtained from The World Bank data catalog, where it was collected from the FAO.

1.2 Data agglomeration

Datasets involving hydropower projects in the Lower Mekong are both sparse and inconsistent across the region. Data agglomeration from multiple sources was necessary to obtain reliable measures of installed capacity across the region during the timeframe of 2000-2020. Regional dam records from CGIAR did not give complete capacity data for Cambodia, Vietnam, and Thailand. State department reports from these three nations were joined to the CGIAR dataset to create a comprehensive view of hydropower capacity in the region. The data acquired from FAOSTAT provided complete information on agricultural producer prices, crop yields, agricultural input prices, agricultural net production, urban and agricultural land-use split, and gross national income, so no agglomeration was needed for these fields. The World Bank database for fishery data was also exhaustive. A common time frame was determined to be 2000-2017 in order to optimize the temporal overlap of the datasets.

1.3 Data validation

Given the majority of the study focuses on the impacts of installed capacity, the aggregate dam dataset was validated against a regional dam registry from the Stimson Center as well as total hydropower capacity reports from each nation to ensure accuracy in data. FAO and World Bank have already cleaned and validated their datasets.

METHODS

2.1 Hydropower

To determine the descriptive scenario of hydropower infrastructure in the lower Mekong river basin, it is first essential to summarize the data from the aggregated hydropower dataset. Excel pivot tables were used to find the desired summary statistics. This method allowed for the segmentation of these statistics by country, which was essential for determining their individual contributions to installed capacity.

For statistical analysis, annual yearly contributions to installed capacity were calculated from the original dataset. When applicable, a general method was applied for metrics compared against installed capacity. This statistical method included a primary regression analysis to understand correlation of each metric with annual capacity. Then, annual yearly contributions were recorded into binary variables to differentiate between years of high growth and low growth. Sample testing was then conducted to understand the correlation between various metrics and this binary indicator.

2.2 Economy

The analysis tools used were Excel and Minitab. Excel was primarily used to store data and create time series graphs for each economic metric's growth compared to installed energy capacity per year. The purpose of these time series plots was to test, visually, if there were any upward or downward correlations in need of deeper statistical analysis. The benchmark metric used in this section's testing was installed energy capacity per year (in megawatts). With this metric, it is important again to note the separation described above between "*big*" and "*small*" years of installed energy capacity. When statistical analysis was needed, the data was transferred into Minitab to run statistical correlation testing to a 95% confidence level via 2-way t-tests and box plots. T-tests were utilized to form and test a hypothesis to try and prove any correlation between installed energy capacities per country and their various economic metrics' growth rates. If the resulting p-value was below .05 then the null hypothesis was rejected, further the alternative hypothesis was accepted. Boxplots were then sufficient to test whether the *"big"* or *"small"* years were actual drivers of the various economic metrics' growth rates. These metrics were: Gross National Income per-capita (GNI) and Energy Consumption.

2.3 Agriculture

Excel and Minitab were used heavily in this analysis to perform regression tests and sample mean tests on the data to gain a clearer picture of trends and relationships between agricultural indicators and installed hydropower capacity levels.

Starting our analysis of the agricultural industries of the region, we take a closer look at rice crop yields in the Lower Mekong over the last 20 years. Rice is the staple crop in the region and crop yields of rice serve as key indicators in evaluating whether crops adequately provide enough food for the internal food supply, livestock, and energy sources. We then analyze the Agricultural Net Production Index (ANPI) of each country in the Lower Mekong region. This metric is the most comprehensive in terms of quantifying the efficiency of farms in the region. To obtain the index, the aggregate production for a given year is weighted by the costs of production inputs throughout the period. In layman's terms, ANPI is "Production – Feed – Seed." With the use of Minitab, 2 sample T-tests were run in order to determine statistically significant correlations between "small" years and "big" years in relation to crop yields & ANPI's recorded. We attempted to draw conclusions to a 95% confidence level in our hypothesis testing.

2.4 Land-Use

Excel and Minitab were used heavily in land-use analysis. Data from the past 20 years related to land-use split was analyzed for each of the lower Mekong region countries (Cambodia, Vietnam, Thailand, and Lao PDR). Land-Use split is commonly focused on three classifications of land areas: Forestry, Agricultural, and Urban. The two classifications of significant importance are agricultural land and urban land. Time series were used on agricultural and urban land split to determine general growth trends in each of the lower Mekong countries. To perform two sample T-tests on the collected land-use data, years have once again been classified as "*big*" and "*small*". Conclusions will be drawn at the 95% confidence interval.

2.5 Fisheries

Excel and Minitab were used to analyze the World Bank data from 2000-2016 as well as the installed capacity hydropower data. Regression tests were carried out at a significance level of .05 in order to determine relationships between installed capacities and fishery productions. The metrics used were fishery yield, installed capacity, and year over year fishery percent change. Fishery yield theoretically included all capture fisheries including subsistence and aquaculture farms. Yearly installed capacity was used as opposed to the consideration of individual dam construction because the fishery capture data was an estimate for each year. Year over year percent change was used in order to attempt to correlate hydropower implementation with dips in percent change.

RESULTS

3.1 Hydropower

Since the year 2000, hydropower infrastructure and investment has expanded greatly in the Lower Mekong River Basin. In total, over 500 hydropower projects have begun operation or have been commissioned during this timeframe. Of these, over 60 are large scale hydropower dams. New hydropower projects have contributed to a hydropower capacity increase of over 37,000 MW throughout the last 20 years.

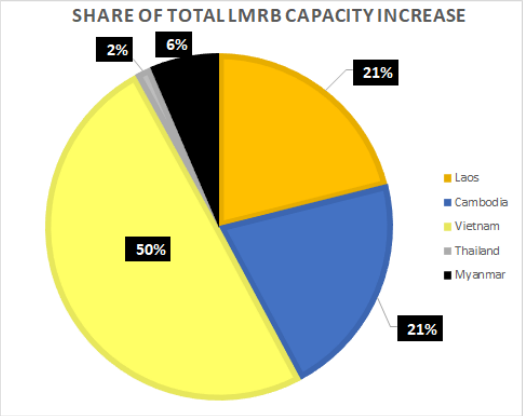

FIGURE 2: Increase in capacity during 2000-2019 in the Lower Mekong River Basin

Figure 2 shows the contribution of each LMRB country to the total regional capacity increase since 2000. Hydropower projects in Vietnam account for 50% of this growth, with Laos and Cambodia each contributing 21%. The entire capacity of the region is not shown, and preexisting hydropower infrastructure likely influences these numbers. The data highlights each country's stance to 21st century hydropower development in relation to the rest of the region.

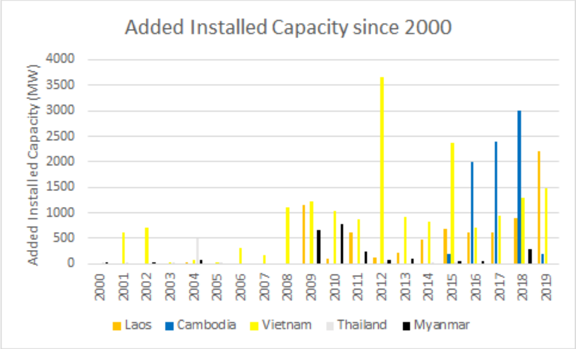

FIGURE 3: Annual contributions to installed capacity 2000-2019

Figure 3 shows the distribution of installed capacity by nation and year. The data suggests that installed capacity does not increase linearly over time and that, specifically, this increase is due to sporadic contributions over time. Outliers in the data correspond to years in which countries in the LMRB completed major hydropower projects, and it can be seen these major hydropower projects greatly influence national and regional totals for installed capacity.

3.2 Economy

The goal of the economic analysis is to first use the t-tests to look for relationships between variables. The box plots then show how the independent variable, installed energy capacity, affects the differing dependent variables' distributions and proves if they are mutually driving growths.

3.2.1 GNI per-capita

The null hypothesis in this 2-way t-test was that each country's mean GNI per-capita growth was the same in *"big"* and *"small"* years, while the alternative hypothesis tests the opposite. The p-values for Myanmar, Cambodia, Lao, Thailand, and Viet Nam were .583, .268, .486, .00, and .44 respectively. These results prove the null hypothesis to be true for all but Thailand. For further clarity, it was then necessary to test for causation via box plot analysis. The x-axis in Figure 4 shows *"small"* and *"big"* years while the y-axis represents the growth rate of

GNI per-capita. Thailand, in this testing section, can be treated as an outlier because only one data point in group 1 does not meet the tests assumptions. We can deduce from these plots that in all countries but Thailand there is a higher mean growth rate of GNI per-capita in *"small"* years. This proves that, while installed capacity and GNI per-capita are both growing, installed energy capacity is not a driver of GNI per-capita growth. In fact, GNI per-capita growth is slowing in *"big"* installed capacity years.

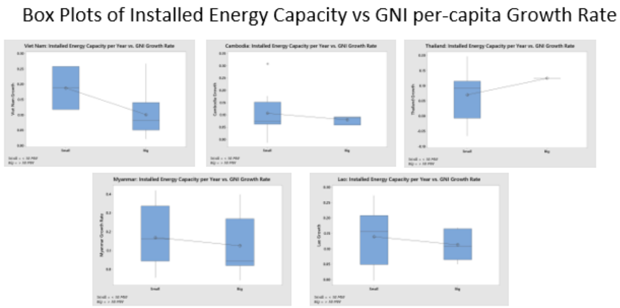

FIGURE 4: Distributions of GNI growth rates between years of "small" and "large" installed energy capacities.

3.2.2 Energy Consumption

The null hypothesis in this 2-way t-test is that the mean growth rates of energy consumption were the same in *"big"* and *"small"* years. Every country's p-values ranged from .416 to .615, proving that we can accept our null hypothesis and further conclude that in years of *"big"* or *"small"* installed energy capacities, energy consumption is not significantly different. However, boxplot analysis is necessary to test for causation between *"big"* and *"small"* years. As seen in Figure 4, boxplots prove that in *"big"* years, the mean growth rate of energy consumption (y-axis) is raised considerably from ~9% to ~12%. From these tests we found that the growth between installed energy capacity and energy consumption both grew significantly from 2000 to 2017, however the two factors do not drive each others' growth.

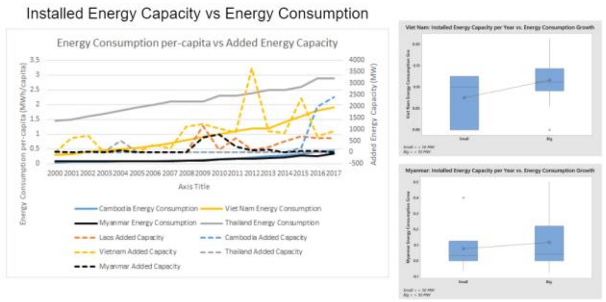

FIGURE 5: Installed Energy Capacity versus Energy Consumption in the Lower Mekong Region shown in time-series and box plot analysis.

3.2.3 GINI Index

The GINI index measures income inequality by serving as a metric for income distribution across a given economy. A GINI index of 0 represents perfect equality, while an index of 1 represents perfect inequality. In Laos, income inequality is severely impacted by the development of new hydropower infrastructure. Government officials and the wealthy profit most from dams as the financial benefits of hydropower generation and export rarely reach the community level. Laos' rapid installment of hydropower dams has contributed to a GINI index increase from 32.6 in 2002 to 41.1 in 2018. However, other countries have seen an opposite response to development. Thailand's increase in hydropower capacity correlates with a decrease in GINI index from 35.46 in 2004 to 30.76 in 2012. Other nations in the Lower Mekong River Basin have either experienced a consistent GINI index over the time period or have not reported the required figures for drawing an inference.

3.3 Agriculture

Investigating the rice crop yields of each country in the region over time, we see the annual growth rate lies between roughly 2-3% in most countries. The outlier is Thailand, which has not experienced the levels of growth that the rest of the region has with an annual growth rate of 0.99%. We then look at crop yields as they relate to the timeline of the implementation of hydropower systems in the region in an attempt to find a relationship between the two. After running sample population tests with the "big " and "year" delineations, we summarized our findings in (see Table 1). We see in our results that in Lao PDR, Cambodia, and Vietnam, our tests output a p-value of <0.05. This means we reject our null hypothesis that rice crop yields are equal in "big" and "small" years in these countries, with rice crop yields being significantly higher in Lao PDR and Cambodia in the "big" years, while being significantly lower in "big" years during Vietnam. In Thailand, we cannot make any conclusions about the sample means of rice production at a 95% confidence level. Therefore, we observe that countries in the Lower Mekong may be feeling unique effects from hydropower implementation on their rice production quantities as we do not see a trend standard across the region. Overall, we do see rice crop yields increase in years when more hydropower capacity is installed.

Country	Rice Crop Yields Avg. (<50 MW year)	Rice Crop Yields Avg. (>50 MW year)	P- Value
Lao PDR	33,844 T	39,895 T	0.002
Cambodia	25,384 T	34,546 T	0.000
Thailand	50,138 T	52,375 T	0.499
Vietnam	29,822 T	26,895 T	0.008

Table 1: Results of 2 Sample T-Tests of Rice Crop Yields

Results of regression analysis of ANPI compared to installed hydropower capacity show that ANPI has grown expectedly over time, and that generally ANPI values are higher in years with more installed hydropower capacity (see Table 2). We see from this table that in Lao PDR, Cambodia, and Thailand, our tests output a p-value of <0.05. This means we reject our null hypothesis that rice crop yields are equal in "big" and "small" years in these countries, with rice crop yields being significantly higher in Lao PDR and Cambodia in "big years", while being significantly lower in "big" years during Thailand. In Vietnam, we cannot make any conclusions about the sample means of rice production at a 95% confidence level. Therefore, we observe another non-standardized impact of hydropower implementation across the region. However, we do note that the average ANPI is greater in years where more hydropower capacity is installed in the countries of Lao PDR, Cambodia, and Vietnam.

Country	ANPI Avg. (<50 MW year)	ANPI Avg. (>50 MW year)	P- Value
Lao PDR	97.7	166.1	0.002
Cambodia	122.1	181.5	0.000
Thailand	112.0	100.1	0.004
Vietnam	106.8	113.4	0.632

Table 2: Results of 2 Sample T-Tests of Agricultural Net Production Index (ANPI)

3.4 Land-Use

Over the past 20 years, as installed hydropower capacity has increased, agricultural land-split increased in all four of the countries studied for land-use changes (Lao PDR, Cambodia, Vietnam, Thailand) at different rates. The highest increase in agricultural land percentage was in Vietnam with a 39.04% increase from the year 2000-2017. Generally, trend lines for land-use split across these four countries remained relatively linear over the past two decades. There was, however, one anomalous year for the country of Vietnam. From the year 2014 to 2015, Vietnam's agricultural land split increased by 11.71%. Notably, 2015 was the second largest year for installed hydropower capacity in Vietnam over the past two decades. Although there may be some slight correlation between installed capacity and agricultural land-use split, it cannot be proven at a statistically significant level that higher installed capacity leads to higher or lower agricultural land split. The same can be said of urban land-split in relation to installed hydropower capacity.

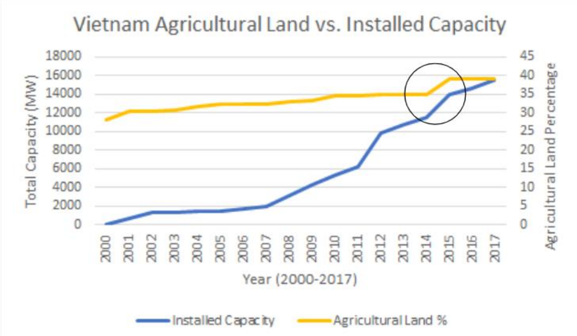

FIGURE 5: Variation of installed capacity and agricultural land use in Vietnam.

3.5 Fisheries

The analysis of Laos and Vietnam showed that an increase in total capacity appears to be an accurate predictor of total fishery production as seen in Fig. 6. While this would seem to contradict the claim that fishery production is decreasing, much of this can be explained through the way in which fishery data is reported. Figures that show that there is an increase in capture fishery production can be at least partially attributed to increasingly accurate data collection methods over time. Historically, official figures measuring fishery production are regarded as inaccurate due to the fact that certain aspects of production such as subsistence fishing have not been included [5]. What can be seen in Fig. 7 is the highly sporadic nature of the percent increases. This seems to back up the claim that there are differences in reporting as these jumps and dips in percent increase cannot be fully explained by installed capacity data.

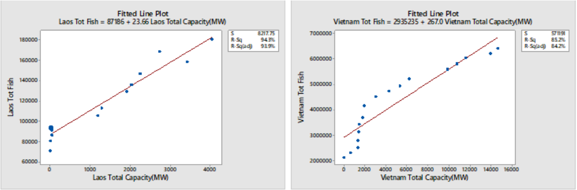

FIGURE 6: Regression testing for installed capacity and capture fishery production

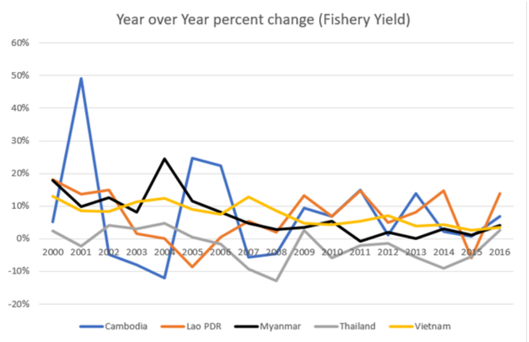

FIGURE 7: Year over year percent change for capture fishery production

CONCLUSION

The study aims to provide a descriptive picture of effects of the current state of hydropower implementation in the Lower Mekong Basin through the use of quantitative data analysis. The challenge here is that we rarely see a uniform impact of hydropower across all countries in the region. In fact, we see some contradicting trends when examining the impact of hydropower implementation on agriculture. Analysis of the data gathered from some regions of the Lower Mekong show conclusive evidence that as more hydropower is installed, rice production in Vietnam decreases and farm efficiency in Thailand decreases. So, while we see periods of growth in some regions, hydropower does not have a universally positive impact on the agricultural industry.

From the perspective of land-use, there was little statistically conclusive evidence that installed hydropower capacity had an effect on land-use split of Mekong countries. However, as installed capacity has continued to grow in the past two decades, land-use split trends showed consistent growth in urban and agricultural land.

Fishery data analysis did not back up the commonly held claim that hydropower infrastructure has a negative impact on fish yields. However, the state of the data points to a larger issue with reporting in the Mekong region.

As relevant stakeholders continue to explore how hydropower can best be implemented going forward, we stress that the importance of a similar analysis to ours is paramount in accurately predicting the holistic effects of implementation across the region. Climate change will continue to pose a threat to our way of living, and we must ensure that its negative effects are not compounded by sub-par implementation of renewable energy sources such as hydropower.

The drastic growth in hydropower dams from 2000-present theoretically provides opportunity for prosperity within the surrounding Mekong region. We would expect these opportunities to be capitalized upon by the countries hosting each dam, however it is becoming increasingly more apparent that this isn’t the case. Markers of personal well-being and prosperity as granular as personal income levels are slowing as hydropower dam development is only continuing to gain momentum. This begs the question: If the natural inhabitants of the Mekong Region are not directly benefiting from each dam put in place, who is making the call to rapidly urbanize? And why?

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