Baseline Econometric Model and Solar Energy Requirement for Potential Hydrogen Demand in Tarlac, Philippines

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Abstract

This study aims to build a baseline econometric model for the possible development of green hydrogen production in Tarlac. Scenario analysis will consider hydrogen produced from renewable solar energy as an alternative energy carrier in the fuel mix for electricity generation in Tarlac to achieve sustainable economic growth and improve energy security while minimizing carbon emissions and improving resource efficiency. Tarlac is the chosen area to be considered in this study because this is where New Clark City is being established. New Clark City is a 9450-hectare disaster-resilient, environment-friendly, integrated urban development metropolis. It is important to build the baseline econometric model before proceeding with scenario generation. The parameters used are determined from available historical data through statistical procedures. The basic assumption is that the relationships between the independent and dependent variables that existed in the past will continue to be true in the future. The energy demand data and the continuous predictors were used to build a baseline econometric model for potential hydrogen demand in Tarlac, Philippines. Model equations were obtained using stepwise regression analysis. These model equations were used to forecast the energy demand up to 2032. These forecasted energy demands will be used in scenario generation to integrate green hydrogen production. Preliminary assessments of green hydrogen scenarios that are based on the assumption of renewable energy surplus generated from solar power plants in Tarlac are discussed. The forecasted demand will be used to assess the scenario generation in integrating green hydrogen in New Clark City. The proposed energy management strategy of storing surplus renewable energy, such as green hydrogen, for the power sector has the potential to impact various stakeholders, including industries and the government, significantly. This strategy aligns with transitioning to cleaner and more sustainable energy sources, contributing to national and international environmental targets. Adopting green hydrogen storage can contribute to energy security by diversifying the sources of power generation.

Keywords: baseline econometric model, continuous predictors, green hydrogen, scenario generation

1. Introduction

During the most intense period of forced confinement in early 2020, daily global CO2 emissions may have been reduced by up to 17% compared to the mean daily CO2 emissions in 2019. The total annual reduction in CO2 emissions was estimated to be between 4.2% and 7.5% compared to 2019 levels. However, an emission reduction of this magnitude will not cause atmospheric CO2 levels to decrease at a global scale [1]. This means that in the short term, the impact of COVID-19 confinement measures cannot be differentiated from natural year-to-year variability. Structural and transformational changes in our global energy production and consumption will be needed for continued long-term reduction. A sustainable energy transition is urgently needed to support continuous economic growth amidst the challenging backdrop of resource depletion and climate change [2].

Hydrogen is expected to play an important role in making fundamental changes to our energy systems. It can constitute a key part of the solution to climate change. There is a growing interest in hydrogen production as different countries around the world explore and execute decarbonization strategies. Hydrogen is not an energy source but a chemical energy carrier, also known as an energy vector. As a molecule, it is a colorless, odorless, non-toxic gas. It bonds readily with other elements, making it extremely rare in its free form and requiring transformation to produce hydrogen that is useful for energy storage and transport. It is an energy carrier with some of the energy required to produce hydrogen released subsequently at the point of use – usually as heat through combustion or as electricity in a fuel cell [3]. Hydrogen is produced from a process called electrolysis, which uses only renewable power and water to create pure hydrogen, and water is called green hydrogen. Different projects, research, and feasibility studies on green hydrogen production in recent years have been prompted by the significant decline in solar photovoltaic and wind generation costs. Green hydrogen, which is also often called "clean hydrogen," "renewable hydrogen," or "low-carbon hydrogen," is, by definition, the hydrogen produced with water electrolysis using electricity from renewable energy sources. Using renewable energy, green hydrogen production does not generate CO2 emissions at any point [4]. It is a game changer and has gained wide acceptance as an energy carrier due to its decarbonization potential [5].

Hydrogen is a versatile energy carrier that has the long-term potential to be the ideal complement to renewable-generated power. It can be a solution for the integration of renewable energies into the electricity or gas grid. Electrolyzers can absorb the excess electricity produced from renewable energies when the demand is low and transform it into green hydrogen [6]. Green hydrogen can be stored for long periods and can be used in periods when variable renewable energy is not available for power generation with stationary fuel cells or hydrogen-ready gas turbines [7]. Water electrolysis technology is seen as the most promising green hydrogen production method, assuming that the electrical energy used to power the water electrolyzer comes exclusively from renewable energy sources. Renewable energy sources such as wind and solar play the most significant role in green hydrogen production [4].

An energy storage system (ESS) for electricity generation uses electricity (or some other energy source, such as solar-thermal energy) to charge an energy storage system or device, which is discharged to supply (generate) electricity when needed at desired levels and quality. ESSs provide a variety of services to support electric power grids. In some cases, ESSs may be paired

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or co-located with other generation resources to improve the economic efficiency of one or both systems. Hydrogen, produced by electrolysis and used to generate electricity, could be considered a form of energy storage for electricity generation [8]. Hydrogen energy storage is another chemical energy storage in which electrical power is converted into hydrogen. This energy can be released again as fuel in a combustion engine or a fuel cell. Hydrogen can be produced from electricity by the electrolysis of water, a simple process that can be carried out with relatively high efficiency provided cheap power is available [9]. Aside from renewable energy sources, especially solar and wind, hydrogen has great potential to be one of the most popular energy carriers and secondary energy sources. The recovery and storage of surplus energy to produce hydrogen plays an important role in designing and building energy systems. There are multiple ways to store hydrogen. The storage technology depends on the storage scale and operating conditions [10]. Thermal energy storage can provide possible solutions to some specific needs like time delay between available power and power production such as solar energy and cogeneration; it can provide security of power supply for healthcare centers, computer server rooms, telecom networks, etc. and finally, thermal inertia and thermal protection [11].

Green hydrogen storage offers scalability due to its deployment flexibility; unlike other energy storage technologies that might be constrained by geographical features, hydrogen storage facilities can be established in diverse locations, making it easier to scale up or down based on demand. It has the advantage of providing long-duration energy storage, making it practical for addressing seasonal variations in renewable energy production. The practicality of green hydrogen storage lies in its ability to mitigate the intermittency and variability of renewable energy sources. It can serve as a reliable backup during low renewable energy generation periods, contributing to grid stability and reliability.

While storing surplus renewable energy as green hydrogen for the power sector is a promising concept, some significant limitations and challenges must be addressed before it can be widely adopted. Converting renewable energy into green hydrogen through electrolysis and then back to electricity through fuel cells involves energy losses at each stage. These losses can be significant, reducing the overall efficiency of the energy management strategy. Both electrolysis and fuel cells technologies are currently expensive, making the large-scale implementation of this strategy costly. There are still limited policies and regulations governing the hydrogen economy. This lack of a clear framework can create uncertainty for investors and hinder the development of the necessary infrastructure. Despite these challenges, research and development are ongoing to improve efficiency, reduce costs, and address the limitations of this energy management strategy. With advancements in technology and evolving policies, green hydrogen storage has the potential to become a more practical solution for integrating renewable energy into the power sector.

Storing surplus renewable energy, such as green hydrogen, for use in the power sector is an energy management strategy that addresses the intermittency and variability of renewable energy sources. Other existing energy management strategies are battery storage, pumped hydro storage, compressed air energy storage (CAES), flywheel energy storage, demand-side management (DSM), and thermal energy storage. Batteries are more suitable for short to medium-term energy storage. They respond quickly to fluctuations in demand and supply, making them well-suited for stabilizing the grid in the short term. Green hydrogen storage offers longer storage durations than batteries. Hydrogen can be stored for extended periods without significant degradation. Pumped hydro has been a traditional and proven technology for energy storage. However, it requires specific geographical features like elevated terrain, which limits its applicability. Unlike pumped hydro storage, green hydrogen storage is not limited by geographical constraints. It can be deployed in various locations, making it more versatile in terms of site selection. CAES involves compressing air and storing it in underground caverns. Geological conditions and energy efficiency may limit it. Green hydrogen storage can be more scalable and flexible than CAES, which often requires specific geological formations for effective implementation. Flywheels are efficient for short-duration energy storage and quick response times but may not be suitable for long-term storage. Green hydrogen can offer longer-term storage compared to flywheels. It can be a more suitable solution for seasonal storage needs. DSM involves optimizing energy consumption patterns to match the available supply. It focuses on shifting demand rather than storing surplus energy. Green hydrogen is more of a supply-side solution. It can complement DSM by providing a reliable source of stored energy to meet demand during periods of low renewable generation. The thermal storage strategy involves storing heat for later use, which can be suitable for specific applications but may have limitations regarding efficiency and scalability. Green hydrogen does not involve the direct storage of thermal energy. However, it can be used together with technologies like concentrated solar power for integrated energy systems.

Green hydrogen produced through electrolysis using renewable energy sources can significantly contribute to decarbonizing the power sector if it displaces fossil fuel-based generation. Substituting coal with green hydrogen in power generation can lead to substantial carbon savings. Coal-fired power plants are significant sources of CO2 emissions, and by replacing or blending coal with green hydrogen, the carbon intensity of electricity generation can be significantly reduced. Replacing or partially substituting coal with green hydrogen can directly reduce SOx emissions from power plants. This reduction in SOx emissions contributes to improved air quality and helps mitigate air pollution’s environmental and health impacts. The system facilitates the integration of intermittent renewable energy sources into the power grid. Surplus energy generated during high renewable energy production periods can be stored as green hydrogen, acting as a buffer during times of low generation, enhancing grid stability and reducing dependence on fossil fuels. Developing and implementing a green hydrogen storage system can create jobs in the renewable energy and technology sectors. Companies involved in producing, storing, and distributing green hydrogen may benefit from a growing market as the demand for clean energy increases. Continuous research, development, and policy support are necessary to make green hydrogen a viable and cost-effective solution for the power sector.

The proposed energy management strategy of storing surplus renewable energy as green hydrogen for the power sector has the potential to impact various stakeholders, including industries and the government significantly. This approach could create new opportunities for revenue generation by offering green hydrogen as a clean energy source. An increasing demand for green hydrogen could stimulate growth in the renewable energy sector, particularly in areas with abundant renewable resources. Companies involved in solar, wind, and other renewable technologies may experience expanded opportunities. Industries engaged in hydrogen production and storage technologies will likely see a surge in demand. This includes manufacturers of electrolyzers, hydrogen storage solutions, and associated infrastructure. Power utilities stand to benefit from enhanced grid stability and reliability. The ability to store surplus renewable energy as green hydrogen can contribute to smoother integration of renewables into the grid, reducing intermittency issues. Governments may need to adapt existing energy policies and regulations to accommodate and incentivize the integration of green hydrogen storage. This could involve introducing subsidies, tax incentives, or regulatory frameworks to encourage investment in this technology. Building green hydrogen storage facilities can boost the economy by creating new jobs, attracting investments, and helping a hydrogen-powered economy grow. Governments striving to meet climate goals and reduce carbon emissions can find green hydrogen storage as a valuable tool. This strategy aligns with transitioning to cleaner and more sustainable energy sources, contributing to national and international environmental targets. Adopting green hydrogen storage can contribute to energy security by diversifying the power generation sources.

Governments may prioritize strategies that reduce dependence on specific energy resources, enhancing overall resilience. Countries investing in green hydrogen technologies may collaborate internationally to share knowledge, technology, and best practices. This can enhance global competitiveness and accelerate the development and adoption of green hydrogen solutions.

The Philippines' energy mix still generally relies on coal, with about 30.8% of total primary energy supply and 57.2% of power generation in 2020. This reliance on coal has caused the largest portion of GHG emission with 55.9 percent share by fuel source. Several regulations that support further uptake of renewables are under discussion or have been approved in 2019. The Department of Energy (DOE) has established a framework for energy storage and off-grid power development. Under the Paris Agreement, governments have agreed to limit the rise in average global temperature to "well below 2°C" in this century compared to pre-industrial levels. The Philippines' conditional Paris Agreement 2030 nationally determined contributions (NDC) target is rated "2°C compatible". Existing implemented or planned policies are not enough to achieve the country's NDC target. Current policy projections indicate a rapid and ongoing increase in greenhouse gas emissions, which is inconsistent with meeting the country's NDC and the goals of the Paris Agreement [12]. Achieving this goal will require substantial emissions reductions across all sectors. The DOE is looking at hydrogen as another viable alternative and cleaner source of energy for the Philippines as it has been globally recognized to provide a diverse range of energy applications, including distributed power, backup power, portable power, and auxiliary power for passenger and freight vehicles, among others. To leverage the potential of hydrogen, the DOE has entered a partnership with the Star Scientific Ltd. of Australia with the signing of a Memorandum of Understanding (MOU) on 27 Janauary 2021. Under the MOU, the Philippine government and Star Scientific expressed their intention to co-work in exploring the use of hydrogen as a fuel for power generation, as well as the role that hydrogen can play in the economy of the Philippines as a whole. A similar collaboration agreement with Tokyo-based Hydrogen Technology Inc. (HTI) was engaged on 7 April 2021 to also investigate the methods on how to employ hydrogen for power supply. The signing of the MOU enables the DOE to fast-track research and development on hydrogen, considering the need to increase the share of renewable energy while adhering to higher environmental standards for a better future [13]. In line with this, a Department Circular No. 2024-01-0001 providing a national policy and general framework, roadmap, and guidelines for hydrogen in the energy sector was issued by the DOE. It is included in this department circular that the prospective uses of hydrogen in the energy sector shall be divided into power generation and electricity storage applications and non-power applications. Power generation and storage shall include the use of electricity produced from hydrogen energy supplied to the grid or as backup and off-grid power supply, industrial-scale energy storage, co-firing with hydrogen derivatives in existing fossil fuel power plants, and hydrogen and its derivatives multigeneration systems [14].

2. Significance of the Study

Scenario analysis is a method of predicting what might happen or the consequences of predicting an object if a certain phenomenon or trend will continue. This analysis has been widely applied to carbon emission evolution trends and emission reduction potentials [15]. Several studies use scenario analysis in energy systems, but only a few have applied it to the hydrogen energy system. These studies are important in developing supportive and appropriate policies. Clear policy targets and specific hydrogen targets are essential for a country's development of its domestic hydrogen economy. It gives stakeholders and investors insight into the government's direction [3].

The scenario analysis study will consider hydrogen as an alternative energy carrier in the fuel mix for the power generation sector in selected areas in the Philippines (specifically, Tarlac) to achieve sustainable economic growth and to improve energy security while minimizing carbon emissions and improving resource efficiency following the principles of circular economy. Tarlac is the chosen area to be considered in this study because this is where New Clark City is being established. New Clark City is 9450 hectares of disaster-resilient, environment-friendly, and integrated urban development metropolis. However, the baseline econometric model must be built first to generate scenarios. An econometric model is a safe forecasting tool, making it possible to consider the trend of indices development in the past and their cause-and-effect interrelations [16]. Econometric models that correlate energy demand with other macroeconomic variables have been proven to be very effective in analyzing the energy consumption pattern of developing countries [17]. This approach is conceptually more attractive for medium-term forecasts, as it relates the demand in physical terms to some socioeconomic determinants. Hence, it is helpful for developmental planning and policy making. This study aims to build the baseline econometric model for potential hydrogen demand in Tarlac.

This study can help companies assess future demand for green hydrogen and decide whether to invest in production facilities or switch to green hydrogen. It can also help energy providers understand the role of solar energy in green hydrogen demand and guide decisions on solar farm development and grid integration. This study can help the government develop strategies to diversify energy sources, reduce reliance on traditional fuels, and modernize the grid to accommodate green hydrogen production. This study can promote clean energy adoption and contribute to a more sustainable energy future in Tarlac.

Although many studies related to hydrogen production have been published in the literature, there have yet to be studies on the baseline econometric model for potential hydrogen demand in Tarlac. Analyzing green hydrogen potential in Tarlac, considering the development of New Clark City, could offer valuable insights not found in studies focused on broader areas. This study is highly relevant in sustainable energy development, particularly for developing economies aiming to achieve sustainable economic growth, improve energy security, and minimize carbon emissions. Green hydrogen is gaining significant attention as a potential clean energy carrier, and understanding its potential demand in specific regions is crucial for informing policy and investment decisions. The focus on Tarlac and its specific characteristics makes the study relevant to policymakers and stakeholders interested in developing green hydrogen production in the Philippines.

3. Methods and Materials

3.1. Baseline econometric model for hydrogen demand

The schematic representation of building the baseline econometric model for hydrogen demand is shown in Figure 1. In the definition of the theoretical model, the mathematical framework that represents the relationship between the independent and dependent variables was selected. The chosen theoretical model is translated into a mathematical equation to identify the functional form. We collected historical data and other relevant factors that might influence electricity sales. The data was then analyzed to identify trends, patterns, and potential relationships between variables. The performance of the fitted model was evaluated using statistical measures like Mean Absolute Error (MAE), Mean Absolute Deviation (MAD), and Mean Squared Deviation (MSD). Lower MAE, MAD, and MSD values indicate a better fit between the model's predictions and the actual sales data. The validity and accuracy of the forecasting model were then assessed.

The parameters to be used are determined from available historical data through statistical

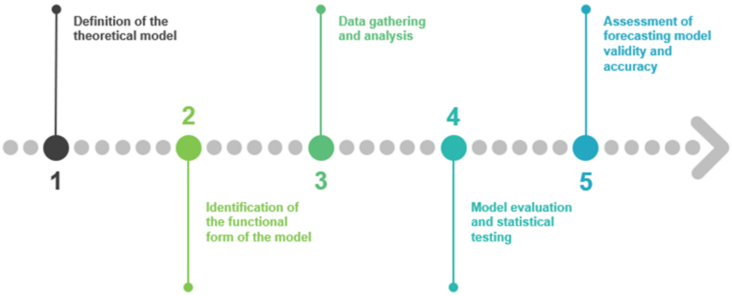

Figure 1: *Schematic representation of building the baseline econometric model for hydrogen demand*

procedures. The basic assumption is that the relationships between the independent and dependent variables that existed in the past will continue to be accurate in the future. The continuous predictors included in the regression analysis are population, gross regional domestic product (GRDP), price, consumer price index (CPI), wholesale price index (WPI), gross capital formation (GCF), and gross value added (GVA). Population typically refers to the number of people in a single area. The continuous predictors used for residential electricity sales are only the population, GRDP, price, and CPI since these are the ones that have effects on the said sales. For commercial and industrial electricity sales, all of the continuous predictors mentioned above, including population, GRDP, price, CPI, WPI, GCF, and GVA, are used. Population growth affects many phenomena, such as the age structure of a country's population, international migration, economic inequality, and the size of a country's workforce. Gross regional domestic product (GRDP) measures a region's economic performance. It covers the value of goods and services produced in the region. Price is the monetary value of a good, service, or resource established during a transaction. The consumer price index (CPI) indicates the change in the average retail prices of a fixed basket of goods and services commonly purchased by households relative to a base year. Tourist arrivals are the number of visitors arriving in a specific location during a given period. Wholesale price index (WPI) is a statistical measure of average changes over time in the wholesale prices of commodities relative to a base year. Gross capital formation (GCF) is investments put in place and measured by the total value of fixed assets or capital formation, changes in inventories and acquisitions, and fewer disposals of valuables. Gross value added (GVA) is an economic productivity metric that measures the contribution of a corporate subsidiary, company, or municipality to an economy, producer, sector, or region. The data needed for this study were gathered through email and online research. The population data is sourced from the World Population Review website [18]. The GRDP, CPI, WPI, and GVA data were obtained from the Philippine Statistics Authority website. The electricity sales and electricity rate data were obtained from three distribution utilities, namely, Tarlac Electric, Inc. (TEI), Tarlac 1 Electric Cooperative, Inc. (TARELCO1), and Tarlac II Electric Cooperative, Inc. (TARELCOII) through the Energy Regulatory Commission in the eFOI or the Freedom of Information. The Freedom of Information (FOI) Program is the response of the government to the call for transparency and full public disclosure of information. It is a government mechanism that enables Filipino citizens to make a formal request to gather data and information regarding government transactions and operations without endangering national security. The number of tourist arrivals in the Province of Tarlac was obtained from DOT Region III through a formal request on the FOI website.

GCF data were obtained from the World Bank's database. Model equations were obtained using stepwise regression analysis in Minitab 17. Stepwise regression analysis is a combination of forward selection and backward elimination. The variables excluded in the model have p-values that are less than or equal to the specified alpha to remove the value, which is 0.1. The variables included in the model have p-values that are greater than the specified alpha-to-enter value, which is 0.05. The resulting model equations include only the most important factors influencing electricity sales. The obtained model equations were used for the years 2013 to 2020. These data are then used to forecast electricity sales for 2021 to 2032 using linear, quadratic, and exponential growth curve models. The best trend analyses were chosen using the accuracy measures (MAPE, MAD, MSD). Mean absolute percentage error (MAPE) measures the average size of the forecasting errors expressed as a percentage of the actual values. Mean absolute deviation (MAD) measures the average size of the forecasting errors in the same units as the data. Mean squared deviation (MSD) measures the average squared difference between predicted and actual values. The chosen trend model exhibited the lower MAPE, MAD, and MSD values.

Ensuring the validity and reliability of our research is paramount. This involves addressing potential biases or limitations in historical data sources used for simulation analysis. To mitigate these issues, we conducted a comprehensive data quality assessment. This involved thorough validation of the historical data through cross-referencing with other reliable sources and official online websites. We also implemented a system of continuous monitoring and updating of data sources to maintain data quality and relevance.

3.2. Scenario generation

Based on the above econometric model of hydrogen demand, scenarios will be generated. The scenarios included in this study will be the following: a) (BAU) Business as usual, b) (HYD1) 5% excess solar energy will be converted to green hydrogen, c) (HYD2) 10% excess solar energy will be converted to green hydrogen. The land area and capital cost needed to produce excess solar energy will be computed by adding 5% and 10% to the forecasted energy demand in 2032. Solar panel efficiency was also determined by estimating the efficiency of the solar panels and the average solar radiation in the area where the solar panels will be installed. The land area required was determined by dividing the total energy production requirement by the product of solar panel efficiency and average solar radiation. The capital cost will include the solar panels, the installation costs, maintenance costs, and any additional infrastructure for the solar energy system.

4. RESULTS AND DISCUSSIONS

Using the historical energy demand data and the values of the continuous predictors, stepwise regression analysis was performed to obtain the model equation. Stepwise regression analysis is a combination of forward selection and backward elimination. The variables excluded in the model have p-values that are less than or equal to the specified alpha to remove the value 0.1. The variables included in the model have p-values that are greater than the specified alpha to enter the value 0.05. Model equations used in forecasting are shown in Table 1.

Estimated populations were computed using the zoning map of New Clark City and the population density in Tarlac shown in Table 2.

The obtained model equations were used to forecast the energy demands up to 2032. Three different trend models were used to forecast energy demands: the linear trend model, the quadratic trend model, and the exponential growth trend model. The accuracy measures (MAPE, MAD, MSD) were used to compare the results from the different time series models. The mean absolute percent error (MAPE) indicates accuracy as a percentage of the error. The mean absolute deviation (MAD) shows accuracy in the same units as the data, which helps to understand the amount of

Table 1: *Model equations used in forecasting*

Tarlac Electric Inc. (TEI)		
Residential	Commercial	Industrial
KWH Sales = -788991474 + 2782 POP – 0.03123 GRDP	KWH Sales = 181575 + 0.07952 GRDP	KWH Sales = 70577489 + 0.0785 GRDP – 21920928 PRICE
Tarlac 1 Electric Cooperative, Inc. (TARELCO1)		
Residential	Commercial	Industrial
KWH Sales = -598451805 + 2428.1 POP – 1043461 CPI	KWH Sales = 7853944 + 3064835 PRICE	KWH Sales = -799083746 + 2507 POP
Tarlac II Electric Cooperative, Inc. (TARELCOII)		
Residential	Commercial	Industrial
KWH Sales = -603999527 + 2430 POP – 1190046 CPI	KWH Sales = -107701972 + 389.5 POP + 0.01393 GRDP	KWH Sales = -795682903 + 2502 POP

Table 2: *New Clark City zoning details*

Area Classification	Area Size (hectares)	Estimated Population
General Industrial	217.04	1,072
Light Industrial	72.76	359
Research & Development	12.04	59
Neighborhood Level Commercial	4.12	20
Medium Density Residential	72.22	357
High Density Residential	41.88	207
Mixed-Use Residential	7.54	37

error. The mean square deviation (MSD) indicates the accuracy of the fitted time series values. Smaller values in the accuracy measures suggested a better fit. Figures 2 to 10 show the models that exhibited the best accuracy measures among the different time series models.

Figures 2 to 4 show the trend analysis plots for electricity sales from Tarlac Electric Inc. (TEI). Figure 1a displays the growth curve model for residential electricity sales from TEI. It appears to capture the general trend of the residential electricity sales data. The accuracy measures suggest an acceptable fit. Quarantine or stay-at-home orders and increased remote work could have led to continuous increased consumption in 2020 compared to previous years. Figures 3 and 4 show the linear trend model for commercial and industrial electricity sales from TEI. Both trend lines suggest a generally increasing pattern in commercial and industrial electricity sales over time, which can be attributed to population growth or increased economic activity. The significant decrease in electricity sales around 2020 for both graphs likely reflects the impact of the COVID-19 pandemic. Business closures and reduced industrial activity would lead to decreased electricity consumption.

Figures 5 to 7 show the trend analysis plots for electricity sales from Tarlac I Electric Cooperative, Inc. (TARELCO1). Figures 3a and 3b display the growth curve models for residential

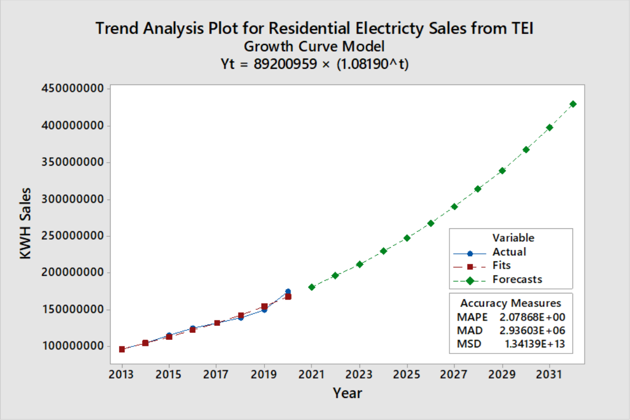

Figure 2: *Growth curve model of residential electricity sales from Tarlac Electric Inc. (TEI)*

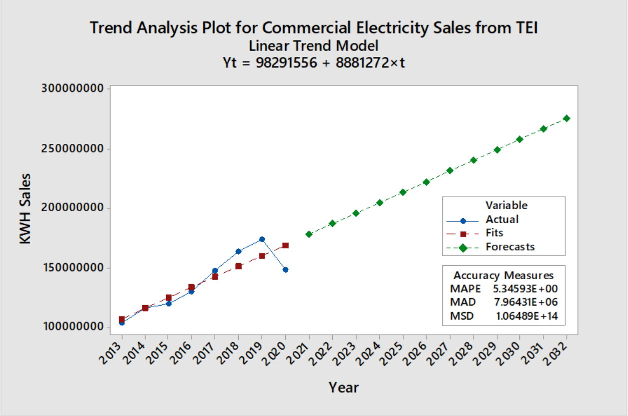

Figure 3: *Linear trend model of commercial electricity sales from Tarlac Electric Inc. (TEI)*

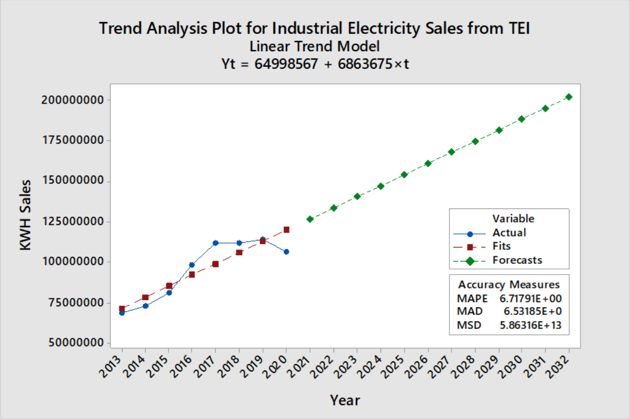

Figure 4: *Linear trend model of industrial electricity sales from Tarlac Electric Inc. (TEI)*

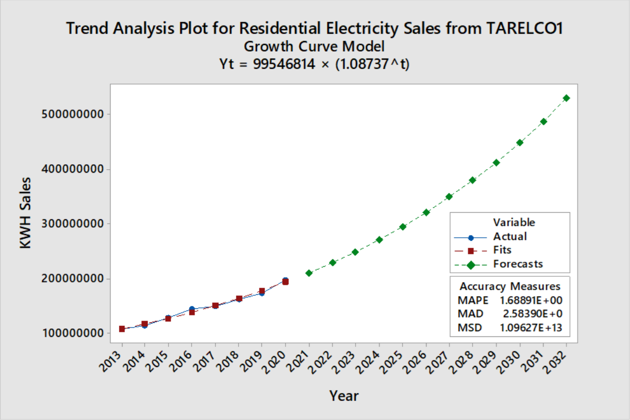

Figure 5: *Growth curve model of residential electricity sales from Tarlac 1 Electric Cooperative, Inc. (TARELCO1)*

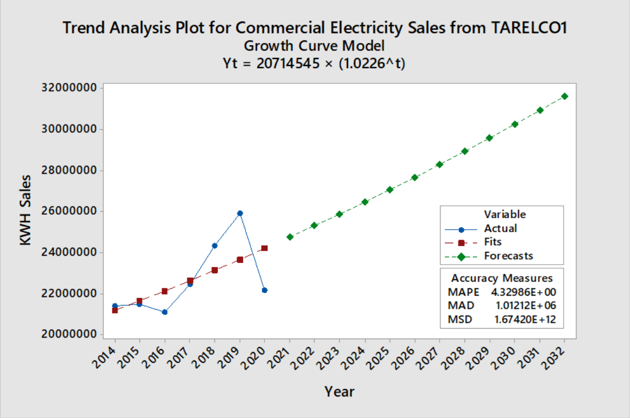

Figure 6: *Growth curve model of commercial electricity sales from Tarlac 1 Electric Cooperative, Inc. (TARELCO1)*

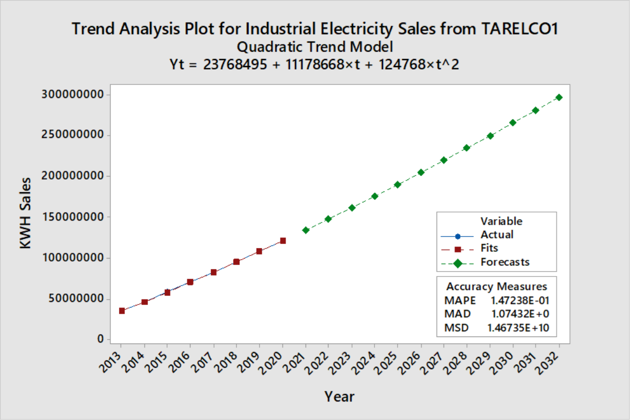

Figure 7: *Quadratic trend model of industrial electricity sales from Tarlac 1 Electric Cooperative, Inc. (TARELCO1)*

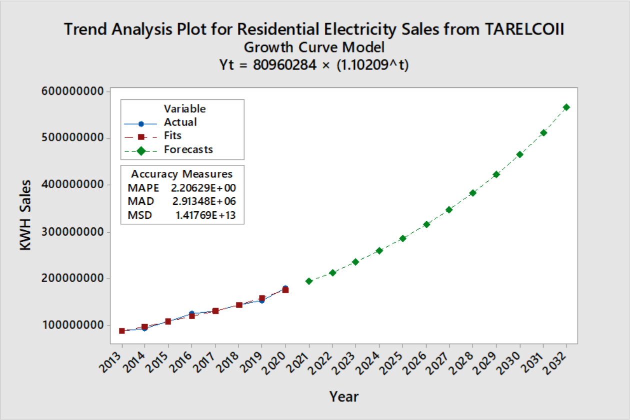

Figure 8: *Growth curve model of residential electricity sales from Tarlac II Electric Cooperative, Inc. (TARELCOII)*

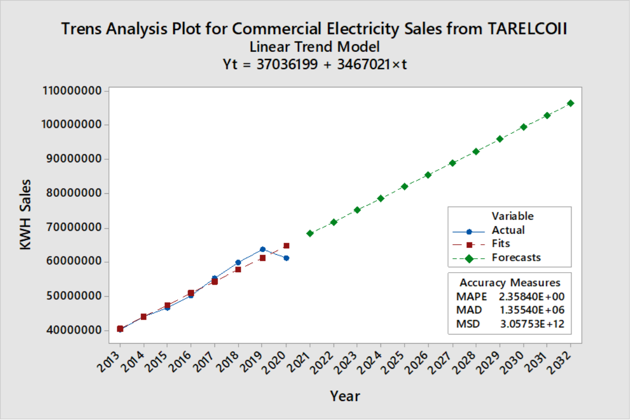

Figure 9: *Linear trend model of commercial electricity sales from Tarlac II Electric Cooperative, Inc. (TARELCOII)*

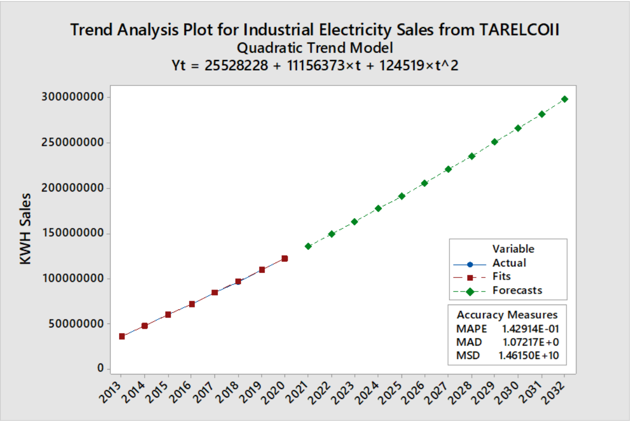

Figure 10: *Quadratic trend model of industrial electricity sales from Tarlac II Electric Cooperative, Inc. (TARELCOII)*

and commercial electricity sales from TARELCO1. Figure 3b shows the significant decrease in commercial electricity sales around 2020, reflecting the impact of the COVID-19 pandemic, which led to business closures. Figure 7 shows the quadratic trend model for industrial electricity sales. It captures the general trend of the residential electricity sales data. The accuracy measures of the three graphs suggest a moderately good fit to the data.

Figures 8 to 10 show the trend analysis plots for electricity sales from Tarlac II Electric Cooperative, Inc. (TARELCOII). The figures from TARELCOII display the growth curve model for residential electricity sales, the linear trend model for commercial electricity sales, and the quadratic trend model for industrial electricity sales. Figure 10 shows the quadratic trend model for industrial electricity sales. The accuracy measures of the three graphs suggest a moderately good fit to the data.

The average mean absolute percentage error of the forecasted energy demand are 4.71%, 2.06%, and 1.57% for TEI, TARELCO1, and TARELCOII respectively as shown in Table 3. These results, consistent with the study of Haider, et al., provide a strong validation of our methodology. In their study, Haider, et al. compared different machine learning methods (Prophet, SGD, SARIMAX) used in forecasting hydrogen production by their mean absolute percentage error (MAPE) [19]. Prophet, SGD and SARIMAX resulted to mean absolute percentage error of 3.71%, 3.58% and 9.08%, respectively. The forecasted energy demands will be used in scenario generation to integrate green hydrogen production in the power sector.

Table 3: *Mean absolute percentage errors of each sector of the different distribution utilities in Tarlac*

	Residential	Commercial	Industrial	Average MAPE
TEI	2.0787	5.3459	6.7179	4.7142
TARELCO1	1.6889	4.3299	0.1472	2.0553
TARELCOII	2.2063	2.3584	0.1429	1.5692
				2.7796

actual data except for the residential electricity sales of TARELCOII and TEI's commercial and industrial electricity sales. A noticeable sudden increase in electricity sales to the residential sector of TARELCO I and II may have contributed to the difference in forecasted data. This is probably because of the shift to remote work and online activities during the pandemic—the lockdown measures, necessitating individuals to remain in their residences, potentially increased residential electricity consumption. The discrepancies in the actual and forecasted data in the commercial and industrial sectors of TEI may be brought about by a sudden decrease in electricity consumption due to the global COVID-19 pandemic and the resulting economic downturn. Many industries and businesses temporarily closed or reduced operations during the pandemic. Lockdowns, social distancing measures, and supply chain disruptions reduced electricity demand in commercial and industrial sectors.

Table 5 below shows the forecasted energy demand by 2032 using the baseline econometric model. MWh for the proposed New Clark City Solar Farm were computed using the peak sun hours per day, as shown in Table 6.

The list of existing grid-connected solar power plants in Tarlac as of June 2023 is shown in Table 7. Installed capacity is the nameplate capacity. It is the full-load continuous gross capacity of a unit under specified conditions, as calculated from the electric generator nameplate based on the rated power factor. While dependable capacity is the maximum capacity when modified for ambient limitations for a specified period of time, such as a month or a season.

The data used in the computation for the additional solar energy needed to meet the forecasted

Table 4: *Comparison between the actual historical data and the forecasted energy demand for 2021*

		Residential		Commercial		Industrial	
	Year	Actual	Forecasted	Actual	Forecasted	Actual	Forecasted
TEI	2019	149,012,458		175,064,792		111,762,983	
	2020	175,486,303		147,543,127		106,499,765	
	2021	184,418,004	181,152,477	155,890,552	178,223,001	120,403,279	126,771,642
TARELCO1	2019	173,047,195		25,512,960		111,145,741	
	2020	199,654,119		22,985,780		115,856,933	
	2021	217,204,376	211,562,907	25,344,624	24,760,746	130,203,350	134,482,718
TARELCOII	2019	155,611,444		64,639,216		120,965,824	
	2020	181,592,581		61,089,279		119,720,112	
	2021	194,254,360	194,194,766	63,405,086	68,239,387	132,075,860	136,021,642

Table 5: *Forecasted energy demand (MWh) by 2032 using the baseline econometric models*

	Residential	Commercial	Industrial
TEI	430,617	275,917	202,272
TARELCO1	531,631	31,645	297,249
TARELCOII	565,770	106,377	298,463
Total	1,528,017	413,939	797,984

Table 6: *MWh for the proposed New Clark City solar farm using peak sun hours per day*

Capacity		Peak Sun	1 year	MWh (from installed)	MWh (from dependable)
MW		hours/day	days	41,062	32,850
Installed	Dependable				
25	20	4.5	365	164,250	131,400
100	80			205,312	164,250

Table 7: *List of existing grid-connected solar power plants in Tarlac as of June 2023*

Facility Name	Capacity (MW)	
	Installed	Dependable
Clark Solar	22.3	17.9
Concepcion 1 Solar	20.7	16.6
Concepcion 2 Solar	70.9	56.7
PetroSolar	50.1	40.1
PetroSolar 2	20	16.5
Sta. Rosa Solar	60.1	48.1
Armenia Solar	8.8	7.1
Dalayap Solar	7.5	6
Total	260.4	209

demand, the additional solar energy needed, and the land area required to produce the said additional solar energy in Tarlac were shown in Table 8 and Table 9. Please note that this computation did not include other existing power plants in Tarlac that are not sourced from renewable energy.

Table 8: *Data used in the computation of additional solar energy needed to meet the forecasted energy demand by 2032*

Forecasted Energy Demand 2032 (MWh)	2,739,941
Proposed NCC Solar Power Plant MWh (from Dependable)	164,250
Existing Solar Power Plant in Tarlac MWh (from Dependable)	343,282.5
Peak Sun (hours/day)	4.5
1 year (days)	365
Solar panel efficiency (%)	15.9
Global horizontal irradiance (kWh/m^2)	1945.3

Table 9: *Additional solar energy needed to meet the forecasted energy demand by 2032*

Additional Solar Energy Needed (MWh)		
BAU	5%	10%
2,232,408	2,344,028.84	2,455,649.26

Land Area Required (m^2)		
BAU	5%	10%
7,217,552	7,578,430	7,939,308

Land Area Required (ha)		
BAU	5%	10%
722	758	794

5. CONCLUSION

This study utilized historical energy demand data and continuous predictors to build a baseline econometric model for potential hydrogen demand in Tarlac. Model equations were obtained by using stepwise regression analysis. These model equations were used to forecast the energy demand up to 2032. The different trend analyses that were used in forecasting are a linear trend, quadratic trend, and exponential growth curve trend. The best trend analyses were chosen using the accuracy measures (MAPE, MAD, MSD). The forecasted energy demand's average absolute percentage error is 4.42%, 1.82%, and 2.63% for TEI, TARELCO1, and TARELCOII, respectively. Additional validation was performed by comparing actual electricity sales and the forecasted data in 2021. A notable decrease in electricity sales in 2020, attributed to the global COVID-19 pandemic and economic downturn, was observed. Commercial and industrial sectors faced closures or reduced operations, leading to decreased electricity demand, while residential sectors had increased consumption due to the rise of remote work and online activities.

Preliminary assessments of green hydrogen scenarios that are based on the assumption of renewable energy surplus generated from solar power plants in Tarlac are done. This study includes the energy landscape of Tarlac, presenting preliminary solar farm computations, existing grid-connected solar power plants, and the needed solar energy to meet forecasted demand. The findings provide valuable insights for scenario generation, particularly in integrating green hydrogen production, emphasizing the need for a diversified and sustainable energy strategy in the face of dynamic economic and environmental conditions. The forecasted demand will be used to assess the scenario generation in integrating green hydrogen in New Clark City. It is recommended that the performance of the model selected from stepwise regression be evaluated against other commonly used forecasting methods like ARIMA models in future studies. The proposed energy management strategy of storing surplus renewable energy, such as green hydrogen, for the power sector has the potential to impact various stakeholders, including industries and the government significantly. This approach could create new opportunities for revenue generation by offering green hydrogen as a clean energy source. Governments striving to meet climate goals and reduce carbon emissions can find green hydrogen storage as a valuable tool. This strategy aligns with transitioning to cleaner and more sustainable energy sources, contributing to national and international environmental targets. Green hydrogen storage can contribute to energy security by diversifying the power generation sources. Governments may prioritize strategies that reduce dependence on specific energy resources, enhancing overall resilience. Future research is needed to generate and explore energy scenarios with the integration of green hydrogen in the power sector of Tarlac and to evaluate and determine the possible environmental and economic implications on the energy system due to the green hydrogen technology penetration on the power generation sector specifically CO2 emissions, and the total annual cost of electricity.

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