EVALUATION OF EFFICIENCY OF WASP AND LIPS XP/OP ELECTRICITY PLANNING MODELS IN KENYA

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A Research Paper submitted to the Department of Economics and Development Studies in fulfilment of the requirements for the award of the degree of Master of Arts in Economics of the University of Nairobi.

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DECLARATION

I declare that this is my original work and has not been submitted to any other university for the award of a degree.

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This project paper has been submitted for examination with my approval as the university supervisor

Signature …………………….……………… Date…………………5.12.2022…………

Dr. Kamau Gathiaka

DEDICATION

I dedicate this project work to the Almighty God for enabling me to undertake it smoothly. I also dedicate the work to my family and colleagues who have supported me throughout the entire study period.

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Abbreviations and acronyms

PPA – Power Purchase Agreement

LOLP – Loss of Load Probability

LCPDP – Least Cost Power Development Plan

IAEA – International Atomic Energy Agency

IRENA – International Renewable Energy Agency

LIPS – Laymeher International Power System

KW - Kilowatt

KWh – Kilowatt hours

MW - Megawatt

MWh – Megawatt hours

GW - Gigawatt

GWh – Gigawatt hours

US Dollars – The United States Dollar

MAED – Model for Analysis of Energy Demand

WASP - Wien Automatic System Planning Software

LIPS XP/OP - Is a simulation model customized for Kenya electricity system optimization

PSSE - Power System Simulation Software

ISO – Independent System Operator

BESS – Battery Energy System Storage

Terminologies

Big 4" agenda – It the Kenya government developmental blue print which guide the current government on the areas of focus for the achievement of the economic development.

Installed Capacity – Generating capacity of a power plant that at the manufacturers rating, also called name plate

Effective Capacity – It is the load carrying ability of a power plant, also called dependable capacity

Peak Demand – This is the highest electrical power demand that occurs at a specific period of time.

Scenario Definitions:

Low Scenario - This scenario assumes a slowed growth rate, otherwise called Business as usual

Reference Scenario – The scenario assumes that the economy will grow in in a moderately higher rate.

Vision Scenario – This is an ambitious scenario that take into consideration the implementation of flagship projects under vision 2030

For purposes of this study, only the reference scenario will be considered.

ABSTRACT

Power system planning is a major issue in many electricity producing industries, both in high- and low-income countries due to its complexity and dimensionality. Most countries have applied different models to predict future outcome values with some countries like Kenya using more than one model. However, due to the different assumptions that these models are based on, there is a likelihood of giving different (and sometimes contradicting) outcomes over the same period. As such, thus study was trying to assess the accuracy/reliability of different Electricity Development Plans in Kenya. The study compared two generation plans, the WASP model) and the LIPS XP/OP model Which one is optimal? The study used data from WDI KPLC and KenGen and mean difference as the main analytical tool. The study finding reveal that two models were not accurate in predicting the country's electricity generation between 2015 and 2021 as they all overstated the production from the actual observed values. LIPS XP/OP model had a lower overstated mean than the WASP Model. Additionally, the study revealed that at individual technology level, the WASP model overestimated the geothermal technology generation capacity while LIPS XP/OP model overestimated hydropower and Diesel engine technology generation capacity. The two models significantly differ in prediction of diesel engine technology, import technology, cogeneration technology, wind technology and PV technology with WASP model having overestimated diesel engine technology consumption while LIPS XP/OP estimated import technology consumption; cogeneration technology consumption, wind technology consumption and PV technology consumption. Finally, LIPS XP/OP model performed dismally in all costs while WASP predicted inaccurately least cost in most scenarios. We thus recommend that each of the models be used where it is more accurate and reliable in predicting the true focused values of electricity in Kenya.

CHAPTER ONE: INTRODUCTION

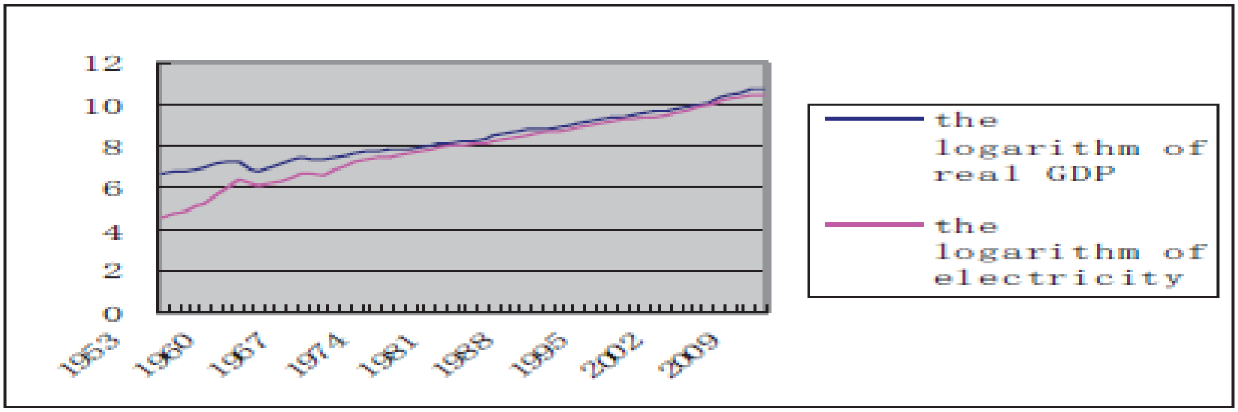
1.0 Introduction

This chapter provides the contextual description of the purpose of this study including the problem, research questions, the study objectives, justification and the line of enquiry to be used in the research.

1.1 Background

Energy resources take a centre stage in the economic development of any country. In particular, provision of adequately reliable, affordable and safe electric power is not only a vital precondition but also an inevitable input to the achievement of any country's development goals. Most empirical studies indicate that there is a very high correlation between the growth in electricity consumption growth and economic development. Electricity consumption is a variable that supports economic growth. A rise in the rate of electricity consumption is shown to have a positive relationship with economic growth (Shengfeng X. et al., 2012).

Figure 1: Real GDP and Electricity consumption in China 1953-2009



Source: Physics Procedia 24 (2012) 56 – 62

Many development agencies and governments have set ambitious plans to ensure universal electricity access world-over. Reforms in the energy sector have boosted the accessibility of electricity both at industrial and domestic level, resulting to a more robust economic growth.

The electricity sub-sector in Kenya is a critical enabler to the implementation of the vision 2030 and the “Big 4” agenda. In the past, the country has depended heavily on biomass, hydrocarbons, electricity and solar as forms of energy (LCPDP report 2013-2033). As the country strives to achieve its development goals, a more reliable, affordable and safe electricity supply is fundamental.

1.1.1 Existing Electricity Supply

Kenya’s electricity supply stands at an installed capacity totalling 2,990MW which comprised of 838.1MW of hydro, 646.3MW of thermal, 863.1MW of geothermal, 435.5MW of wind, 2MW of cogeneration, 170.3MW of Solar power and an off-grid capacity of 34.4MW. The total effective capacity is 2,858MW. On the other side, peak demand stands at about 2,036MW (Kenya Power annual report, 2021).

Table 1: Capacity and Generation mix as at June 2021

Technology	Total Capacity in MW (Installed)	Total Capacity in MW (Effective)	% Share
Hydro	838.1	809.13	28.32%
Geothermal	863.13	805.1	28.17%
Thermal (Fossil Fuel)	586.32	566.42	19.82%
Wind	60	56	1.96%
Biomass	435.5	425.5	14.89%

Technology	**Total Capacity in MW (Installed)**	**Total Capacity in MW (Effective)**	**% Share**
Solar	2	2	0.07%
Imports	170.25	170.25	5.96%
Off-grid	34.4	23.2	0.82%
Total	**2,990**	**2,858**	**100%**

Source: Author's compilation from various Sector reports

A robust exploitation of geothermal resource and development of 310MW wind power in Marsabit county in the recent past has seen increased supply which precariously surpasses demand, a trend which, if not managed will jeopardize the electricity sector and the economy at large. This is because the excess capacity in the system is likely to remain un-utilization hence low returns on investment on already developed projects. It is also likely to hurt the consumers' pockets as they dig deeper into their pockets to pay for the excess power since most electricity supply agreements are based on take or pay contractual arrangement.

1.1.2 Consumption patterns & Peak Demand

Over the years Kenya's electricity consumption as well as Peak Demand have been on an upward trend, growing at an average rate of 4.8% and 4.5% respectively over the last six years (LCPDP report, 2021-2040) as shown in the table 2 and Figure 2 below. This growth is however not adequate to balance the supply.

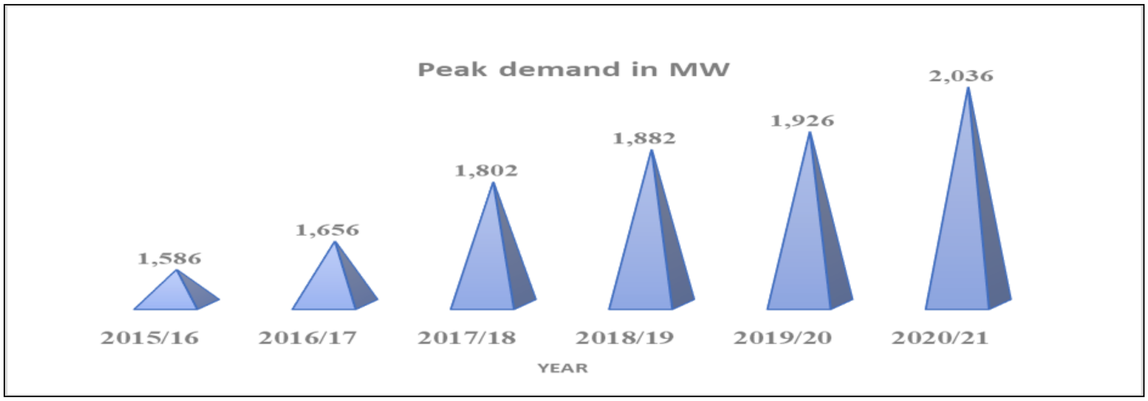
Table 2: Consumption in GWh among various categories

Sales in GWh						
Tariff Category	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**	**2020/21**
Domestic (DC)	2,007	2,138	2,335	2,366	2,508	2,630

Sales in GWh						
Small Commercial (SC)	1,153	1,201	1,222	1,250	1,262	1,326
Commercial & Industrial (SC)	4,104	4,266	4,225	4,462	4,308	4,514
Off-peak (IT)	26	41	33	N/A	N/A	N/A
Street lighting (SL)	40	55	66	68	76	84
TOTAL	**7,330**	**7,701**	**7,881**	**8,147**	**8,154**	**8,553**
% INCREASE P.A.	**4%**	**10%**	**6%**	**3%**	**5%**	**4.8%**

Source: KPLC report, 2021

Figure 2: Peak demand for the last 6 years



Source: Author's Compilation from various sector reports

For the longest time Kenya has focused on the supply of electricity as a driver of the demand. This traditional approach will require a paradigm shift where a combination of demand, system stability, efficiency and cost will form the basis of planning for the power system development.

1.1.3 Importance of Electricity Planning

Globally, a successful implementation of future projects is dependent on plans that a country puts in place to guide the implementation phase. For this reason, the planning phase is a critical stage toward achieving a well-balanced electricity system that ensures efficiency and cost effectiveness for the support of the country’s development initiatives. A good plan must yield a balanced and reliable system, free from fluctuations, down-times and uncertainties. It should be clear and free from political interferences and should also be comprehensive enough to address the issues of reserve capabilities and stability at least cost.

With the growing appetite for implementation of renewable energy worldwide, the plans should be able to accommodate technologies that support the incorporation of renewable energy into the system. Lastly, plans should be dynamic enough to adopt newer planning methodologies that are more robust and detailed to address the shortcomings of the previous ones.

Tools and methodologies used for electricity planning form an integral part of the whole planning phase. A robust planning tool yields close to realistic results while a weak planning tool yields unreliable results that are far from reality. Evolution of planning tools and methodologies ensure integration of new technologies as well as adoption of innovative and more vibrant ways of planning. There are a number of electricity planning tools that that are used by different utilities in the world. While some are universally accessible, others are customer-made and have proprietary right of access.

In Kenya, electricity planning is done by a technical committee comprising of representatives from all the electricity sub-sector institution namely: Ministry of Energy (MOE), Energy & Petroleum Regulatory Authority (EPRA), Kenya Electricity Generating Company PLC (KenGen), Kenya Power (KPLC), Rural Electrification & Renewable Energy Corporation (REREC), Kenya Electricity Transmission Company (KETRACO), Geothermal Development Company (GDC) and Nuclear Power & Energy Agency (NuPEA). The plan is called “The Least Cost Power

Development Plan (LCPDP)". It is a blue print for the implementation of electricity projects in the country. The plan is updated biennially in tandem with economic growth and policy dynamics. The planning process involves a detailed analysis of previous demand growth, demand forecasting, generation expansion planning and transmission & distribution planning, cost analysis and tariff derivation.

1.2 Problem statement

Power system planning is a major issue in many electricity producing industries, both in high- and low-income countries due to its complexity and dimensionality. In planning stage, the cost and reliability are the most essential considerations made in making any decision. Costs may include system investment costs, operational & maintenance costs, fuel costs or even cost of unserved energy to the economy. How to achieve acceptable reliability and costs in the system depends on the adequacy and accuracy of the planning tools/ models that a country chooses to use (Al-Shaalan A.M, 2014).

Over the years Kenya has used different planning tools in carrying out its power system planning, ranging from Energy Demand Analysis Model (MAED) for load forecasting, Wien Automatic System Planning Software (WASP) and LIPS XP/OP for generation planning, and Power System Simulation Software (PSSE) for transmission Planning.

MAED is an International Atomic Energy Agency (IAEA) excel based Model that estimates prospective energy demand dependent on some set assumptions on the social, economic, technological and demographic changes within the area in the medium to long term. It's a powerful tool that models a wide range of energy consumption patterns. Due to lack of data in Kenya, MAED has not fully been utilized to incorporate non-electricity sub-sector energy forecasting. For this reason, the tool is customized to forecast the electricity sub-sector alone.

WASP is an IAEA simulation tool that seeks to optimize generation capacity expansion plan for power generation within identified constraints. It makes use of all probable classifications of more capacity clusters that are required to satisfy demand as well as ensuring that the system is reliable. It shows all costs associated with existing and added generation facilities, reserved capacity and electricity not served to the customers. One of its key strengths is that it uses dynamic programming in generation optimization. The model however is not short of its challenges. It does not factor in transmission network, a key component for development of the overall electricity system. It also does not give the generation output per plant but it aggregates generation per technology. Finally, the Model does not have provision for optimizing intermittent capacity.

In 2015, the country engaged the services of Lahmeyer International, a German-based consultant, to prepare national generation and transmission master plan for Kenya for the period from 2015 to 2035. As an independent consultant, Lahmeyer International dropped the use of WASP and developed a customer-made generation planning tool, LIPS XP/OP. Like WASP, LIPS XP/OP is a simulation model customized for Kenya electricity system optimization under some identified constraint. Unlike WASP, the LIPS XP/OPs' capability goes beyond generation. In addition to more simulations on capacity expansion patterns, it also has capacity to: analyze operation dispatch for any given period, give details on the deficit/excess energy, and track the investment cost & the long run marginal cost and details of lost energy for non-generation (steam venting). It models operational dispatch such that an analyst is capable of analysing dispatch of a typical day, week or year. Its key challenge is that it uses linear programming which makes it slow when running big iterations. Evaluation of the two generation models will be discussed further in chapter three.

PSSE is a computerized electrical power system simulation software that focuses on the operational side of electricity systems. The simulations of the systems include long term transmission expansion planning. The process is in accordance with the capacity expansion planning, short term operational planning and market exploration using mathematical optimization techniques.

Although Kenya has not analytically tested the effectiveness of LIPS/XPOP over WASP, the country has since adopted it for future simulations for generation expansion. This analysis and comparison of the LIPS/XPOP Model and WASP is important in order to ascertain the effectiveness of a planning tool before its adoption and use. Many varying opinions have been expressed by the Kenyan electricity planners on the use of these two models and which one represents more realistic results.

The only approach that has been used to determine which tool to use depends on the planning and capacity building support that the sector gets from the international financial institutions. While this may sound cheap and easy to acquire, lack of proper vetting of the usefulness of the tools may lead to adoption of substandard tools thus giving misleading plans.

The main focus for this research therefore is to assess the effectiveness of LIPS XP/OP in relation to WASP Models for generation planning in order to determine the most appropriate tool for generation planning in Kenya.

1.3 Study Questions

The research questions for this study include:

1.0 How are generation planning models impacting on the national electricity development plans;

2.0 Between LIPS XP/OP and WASP generation expansion models, which one gives better results in terms of matching power demand and supply for Kenyan system?

3.0 What are the implications of past years WASP model-based plans on electricity supply and demand in Kenya?

1.4 Objectives of the study

The main objective is to assess the accuracy/reliability of the Kenya's Electricity Development Plans in order to have an optimized power system that can support the economic development.

The specific objectives are as follows:

- Compare and contrast previous generation plans (2013-2033 and 2015-2035) prepared using WASP and LIPS XP/OP methodologies respectively to identify any gaps that may exist between the two;
- Identify generation projects (both committed and candidates) under various technologies taking into consideration institutional plans and system growth requirement
- Optimize the generation capacity expansion by running WASP and LIPS XP/OP taking note of the demand forecast in order to achieve demand-supply balance

- Compare and contrast results for a more optimal solution

1.5 Justification of the study

With the growth of electricity supply above the country’s demand as seen in the current situation, all the country’s electricity development plans need to address the identified planning challenges in order to ensure a system which will bring down the cost of electricity, guarantees reliability and stability to the end user uptake and hence attract industrial investment, a bulk consumer of electricity in any market.

It is important for the government to allocate resources prudently to the competing priorities. For this reason, each project that is undertaken whether publicly or privately should address the pressing needs of the country. The study will therefore give an insight on the projects that the government needs to undertake in order to have an efficient electricity system that supports the government development agenda.

The study will come up with more realistic supply growth patterns that march the identified demand. The result of this will be a project implementation pipeline that ensures demand-supply balance while addressing the system inefficiencies.

In addition, this study will identify the best planning tool to use in the future generation planning.

CHAPTER TWO: LITERATURE REVIEW

1.0 Introduction

This chapter describes the growing knowledge pertaining the effectiveness of electricity plans across the world under different planning methodologies. It provides highlights on different kind of generation planning approaches, models and their impact on electricity development plans.

1.1 Rationale for Power system plans

The primary objective of Power System Planning is to establish the generation capacity requirement that would satisfy future demand within some identified constraints. Another aim of system planning is the need to develop a favorable transmission grid through which the electricity generated would be transmitted to the bulk load centers. Ultimately, sufficient reticulation facilities must be put in place in order to provide adequate energy from the bulk load centers to the end users. How reliable the production and the supply process would be as well as cost are factors which are of keen interest to the consumers. This makes it imperative from the planning stage, for reliability and cost aspects to be given utmost attention by power system planners and analysts (Debnath K. *et al, 1995).*

A country's energy plan endeavors to analyze and give an overview of complex energy systems. Electricity planning has traditionally played an important role in setting up a regulatory framework within which the electricity market operates. In spite of the different general policy objectives, approaches and models for electricity planning play a fundamental part in energy sector formation and development in both high- and low-income economies.

Capacity Expansion Models are considered important and necessary as they stimulate generation and transmission investments to meet future demand given assumptions about technology cost & performance, fuel prices, policies and regulations. They tend to answer the questions of how different technology mix would be applied so as to meet the future load, cost of service implications on policy change, the variation in consumption and expenditure patterns, what are efficiency and distributional effects of various policy designs among others.

1.2 Capacity Generation Planning Methods and Models

In electricity planning, there exist various ways and methods of evaluating the adequacy of capacity generation. The methods can be divided into two main groups: the analytical methods and the simulation methods. The analytical methods illustrate the system behavior through a mathematical model and assess how reliable a power system is, based on how generation and demand is, from which it calculates the expected reliability indices (Billinton and Allan, 1984). The key merit of these analytical approaches is that it requires low effort when it comes to computation. The simulation methods on the other hand are based on non-chronological and chronological Monte Carlo methods. They calculate the reliability indices by taking trial and error circumstances (Billinton and Li, 1994). The key merits of these approaches are the option of including many system dependencies and features. Current researchers are considering inclusion of renewable energy production-demand elasticities (Matos et al., 2009; Bremermann *et al*, 2014).

Energy systems models create a range of insights and evaluation of supply and demand for power. Since the 20th century, the models are now being greatly embraced in the emergence of harsh climate policy initiatives, energy security and development interests, and growing difficulties due to dynamics in the nature of the 21st century energy systems. Models which relate to energy policy domestically and internationally may be categorized into four: optimization models for energy systems, simulation models for energy systems, power systems and electricity market models, and qualitative and mixed-methods scenarios. The models face four shortcomings which are; resolution of period in time and place, balancing between uncertainty and non-ambiguity, solving the increasing complications associated with energy system while incorporating human behavior and social risks and opportunities (Adam Hawkes *et al*, 2014).

A US Guide to Resource Planning with Energy Efficiency, 2007 defines the major problems, optimal practices, and principal mechanism of incorporating efficiency into electricity supply planning process. It describes the energy efficiency as one of the resources that should be considered in the energy plans. It is presented on the basis of avoided cost (cost saving) in the entire system. It recommends 2 approaches of evaluation namely: i) Use of market-based prices where one values the savings using the current market price of energy and capacity for future delivery, and ii) modelling future electric energy and capacity through production simulations modelling. For the purpose of this study, production simulations will be used in modelling efficiency since electricity markets (auctions) do not exist in Kenya.

1.3 Types of Generation Planning Models

There are different types of generation expansion Models that have been developed world-over. Many of these models differ from each other in one way or the other. Some of these models and softwares are: National Energy Modeling System (NEMS), Regional Energy Deployment System (ReEDS), Integrated Planning Model (IPM), Haiku, MARKAL, AURORA, System Optimizer, PLEXOS, WASP, LIPS among others.

1.4 Limitations of Energy Planning Models

One limitation of the energy planning models is that of harmonization of generation expansion. All electricity generating companies and private investors who assess the suitability if investing in power plants have their perspective of maximizing their gains. This is a practice which should be resigned with the general requirements of the system. An Independent System Operator (ISO) is given the mandate to coordinate to coordinate and control the power system requirements as well as give advice on the required system expansion. By so doing, state companies are able to align with these requirements. It is therefore advised that in addressing the network difficulties, there should be a coordination between generation expansion and power system requirements instead of prioritizing individual or institutional gains. The challenges with the emanate from the uncertainties about the load forecast, difficulties in assigning capacities to be generated, policy and regulatory issues, securing implementation opportunities among others. Thera are also very many stakeholders with conflicting interests who are engaged in the process of planning for capacity expansion. These thus show the need for new approaches and techniques in the planning process in order to ensure flexibility and efficient future electric power systems. A holistic planning approach is recommended where all aspects of the electricity network should be evaluated at as a whole as opposed to personalized aspects. These aspects to be addressed may include; objectively taking into consideration the difficulties in the entire facilities, often with a pecking order which is strongly tied with the structure of the economy, society and environment, individual separate interests of the stakeholders involved (Voropai N.I, 2015).

There exists a noticeable difference in how energy systems are developed in developed world and in the developing world. Developed world aim at reducing adverse climate conditions and gas emissions while developing world are concerned with increasing electricity accessibility through infrastructure development. The models applied lack the consideration of the challenges faced by the developing countries. Key shortcomings arise from the absence of consideration of the low demand for electricity due to issues of accessibility and availability of electricity supply. Other deficiencies also arise from the absence of socio-economic considerations such as the prevailing corruption cases and resulting cost inflation, insufficient quality data quality or information on consumers and the climate change adversities (Debnath, K. B. *et al*, 2018).

The challenges facing developing countries revolve around the primary transformation of energy systems from a complete group of resource to electricity service chains as developing countries seek to provide a sustainable electricity access. It is observed that energy planning is critical and viable. However, a lot of assistance is needed to expand data gathering and accessibility, develop modelling techniques which can easily be accessed, as well as to build nationwide power generating capacities which are sustainable (Mark H. *et al,* 2017).

Lastly, most energy planning models are built in developed countries, often with a biased focus to the nations and areas where they are established. The use of these models in developing countries may not necessarily address the needs of a developing country.

From this literature review, the planning phase of an integrated electricity system is critical. Importantly, there are various areas of focus that a plan needs to address. For example, evaluating demand and supply holistically as opposed to separate considerations, the appropriateness and effectiveness of the planning tools/methodology which are designed to address problems of a specific system, management of stakeholder’s interest and more critically the inputs and assumptions made towards a particular system – *Garbage in garbage out.* These are the planning gaps that this study will be seeking to close in the Kenyan context.

1.5 Factors to consider when selecting a Capacity Expansion Model

When selecting the model to use for capacity expansion, the following factors are worthy considering:

a) **Region** – A region, country or state may have preferences on the models to use for capacity expansion. Many developed countries have their customized models for their internal use. In addition, most developed countries have different characteristics from developing countries and therefore different objectives.

b) **Temporal resolution** – The variability of the seasons is an important factor to consider when choosing which model to use. Incorrect combination of temporal resolution can bring about significant error into model outcomes and inferences in economic perspective.

c) **Time steps** – this is a necessary consideration when planning for new capacities and operational dispatch.

d) **Time horizon** – Some models are designed for shorter periods than others

e) **Representation of generating units** – This presents the technology to be developed as well as the associated costs

f) **Representation of transmission and associated constraints –** Evacuation of electric power is a very important aspect of the overall energy system. The choice of the model should consider power evacuation planning, whether exogenously or endogenously.

g) **Inclusion of renewable energy resource –** Some Models do not consider renewable energy integration. The recent focus on the development of renewable resources implies that the choice of the model must be guided by its provision for renewable energy integration.

CHAPTER THREE: RESEARCH METHODOLOGY

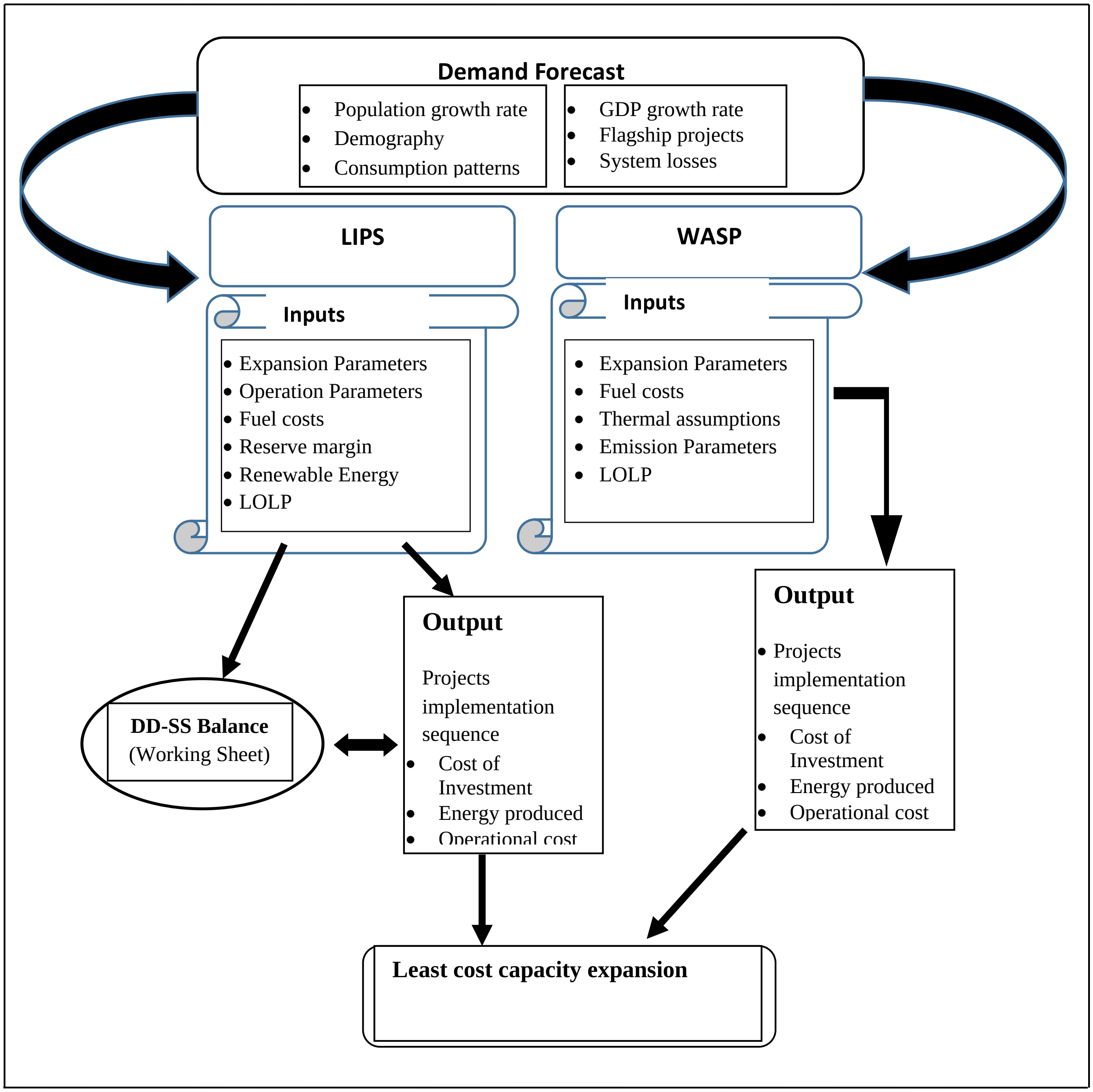
3.0 Introduction

The chapter illustrates the methodology and approach to be used in the analysis and evaluation of the research questions. These include:

3.1 The study Conceptual framework

This study's conceptual framework adopts a comparative approach of WASP IV and LIPS XP/OP Models. First of all, it looks at the demand side where forecasting is carried out to determine the demand outlook in the next 15 years. This forecast is a standard parameter for both the models. The models are assembled together with their inputs and assumptions. This includes a highlight of key deviations from each other and the implication on the outcome and policy decisions.

Figure 3: Conceptual Framework of t Electricity Demand Forecasting



Source: Author

3.2 Study Approach

The initial step will be the review of the LCPDP 3013-2033 data and process. This will help in establishing if there has been any gaps in the planning process based on the WASP model that was used then. In summary the demand-supply for the LCPDP 2013-2033 was planned follows:

3.2.1 Demand Projections

Demand is the driving factor to the determination of the supply growth. In the past, demand has been growing at an average rate of about 4.9% annually in the past six years (Kenya Power annual report, 2021). However, the planned peak demand forecasts of 2013-2033 (WASP) and 2015-2035 (LIPS XP/OP) under reference scenarios indicate that demand will grow at an average of 76.6% and 8% respectively.

A summary of the peak demand growths and consumption patterns according to the two projections are tabulated below:

Table 3: 2013-2033 Demand forecast based on WASP Modeling approach

	Low Scenario			**Reference Scenario**			**High Scenario**		
YEAR	**GWh**	**MW**	**% Growth**	**GWh**	**MW**	**% Growth**	**GWh**	**MW**	**% Growth**
2013	8,010	1,370		8,010	1,370		8,010	1,370	
2015	11,572	1,978	44.4%	12,146	2,069	51.0%	12,514	2,130	55.7%
2018	15,275	2,649	33.9%	17,719	3,034	46.6%	19,282	3,288	54.7%
2025	28,754	5,242	97.9%	42,698	7,480	146.5%	53,657	9,275	182.1%
2030	45,723	8,641	64.8%	81,352	14,446	93.1%	114,502	19,940	115.0%

	Low Scenario			Reference Scenario			High Scenario		
2033	59,135	11,318	31.0%	118,680	21,075	45.9%	179,850	31,237	56.7%
Average growth rate			54.4%			76.6%			92.7%

Source: LCPDP 2013-2033

Table 4: 2015-2035 Demand forecast based on LIPS Modeling approach

	Low Scenario			**Reference Scenario**			**High Scenario**		
YEAR	**GWh**	**MW**	**% Growth**	**GWh**	**MW**	**% Growth**	**GWh**	**MW**	**% Growth**
2015				9,453	1,570	4%			
2016	10,035	1,669	6%	10,093	1,679	7%	10,592	1,770	13%
2020	12,632	2,116	6%	13,367	2,259	8%	16,665	2,845	13%
2025	16,427	2,769	5%	19,240	3,282	9%	25,469	4,431	12%
2030	21,375	3,618	5%	27,366	4,732	10%	39,260	6,833	11%
2035	28,153	4,788	6%	38,478	6,683	8%	58679	10,219	8%
Average growth rate			6%			8%			11%

Source: LCPDP 2015-2035 report

The big variation in the past average demand forecast was attributable to the forecast assumptions. It was anticipated that there would be a robust economic growth which would trigger the demand for power.

A more recent demand projection of 2022-2041 LCPDP has however resulted to a slowed growth rate of 5.34% to reflect more realistic assumptions based on the current trends. This is due to factors like slowed implementation of Vision 2030 flagship projects, lack of incentives to attract industrial customers, poor electricity access among others.

Table 5: 2022-2041 Demand forecast based on LIPS Modeling approach

Year	**Low**			**Reference**			**Vision**		
Year	**GWh**	**MW**	**Growth rate**	**GWh**	**MW**	**Growth rate**	**GWh**	**MW**	**Growth rate**
2021	9440	2036		9440	2036		9440	2036	
2022	9886	2095	2.92%	9999	2121	4.18%	10401	2214	8.73%
2025	11246	2250	2.57%	11720	2353	3.71%	13220	2681	6.65%
2030	14304	2829	5.66%	15576	3099	6.43%	19567	4042	10.11%
2035	18394	3670	5.29%	20449	4106	5.74%	28690	6003	8.30%
2040	23726	4775	5.44%	26900	5440	5.85%	42503	8987	8.29%
2041	24977	5035	5.45%	28433	5757	5.84%	45968	9731	8.28%
Average Growth rate			4.64%			5.34%			8.14%

Source: LCPDP 2022-2041 report

Demand projections will follow the same trend as captured in the 2022-2041 LCPDP report. The demand forecast will guide in establishing the supply requirement for the country. The main factors that are taken into consideration in demand projections include but not limited to: Historical demand and consumption growth patterns; Flagship projects electricity demand requirement; Demography; Macro-economic factors – GDP growth rates; Technical & non-technical losses

The demand forecasting for 2022- 2041 LCPDP report has been identified as the base demand data that will be applied to LIPS XP/OP and WASP IV generation planning models for generation of capacity expansion data. The demand will be limited to the study period of 15 years from 2021 to 2035 which is the study period.

3.2.2 Generation Capacity

On the generation side, 2013-2033 LCPDP plan resulted to a generation mix as represented in the figure below:

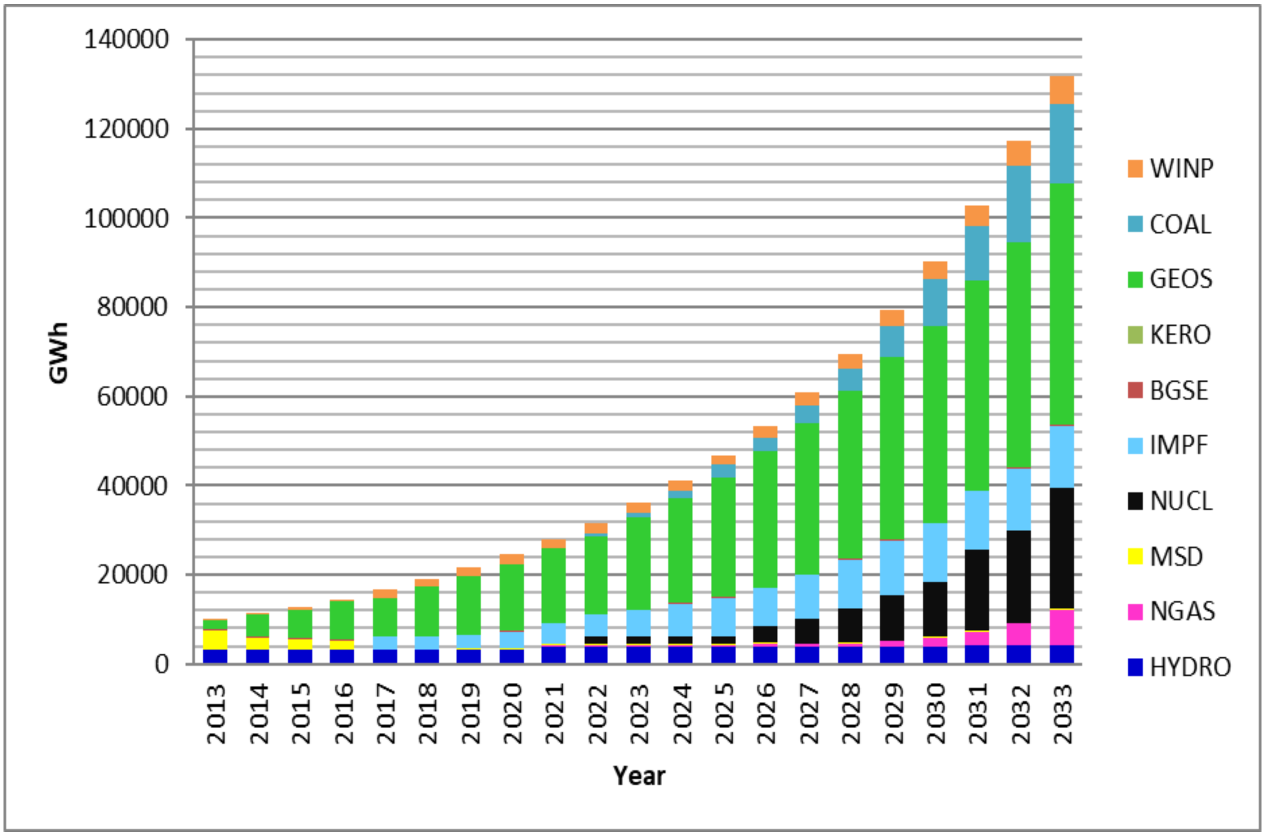


Figure 4: Generation expansion mix in 2013-2033 period using WASP Model

(Source: LCPDP report 2013-2033)

On the other hand, the 2015-2035 Kenya Generation and Transmission Master Plan indicated a capacity generation mix as indicated in the figure below:

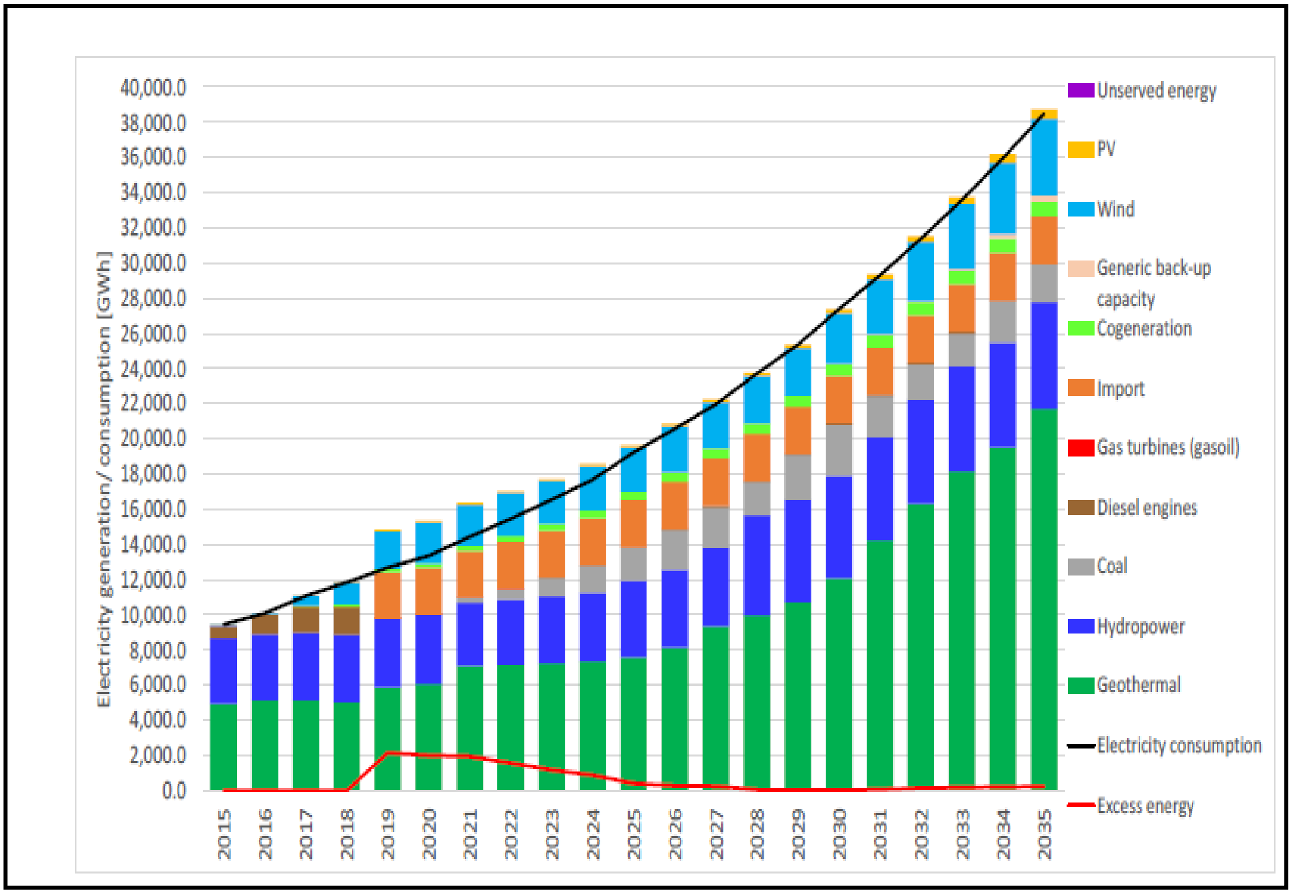


Figure 5: Generation expansion mix in 2015-2035 period using LIPS Model

Source: LCPDP report 2015-2035

A more recent capacity generation plan in the 2022-2041 LCPDP report shows capacity growth at shown in the figure below:

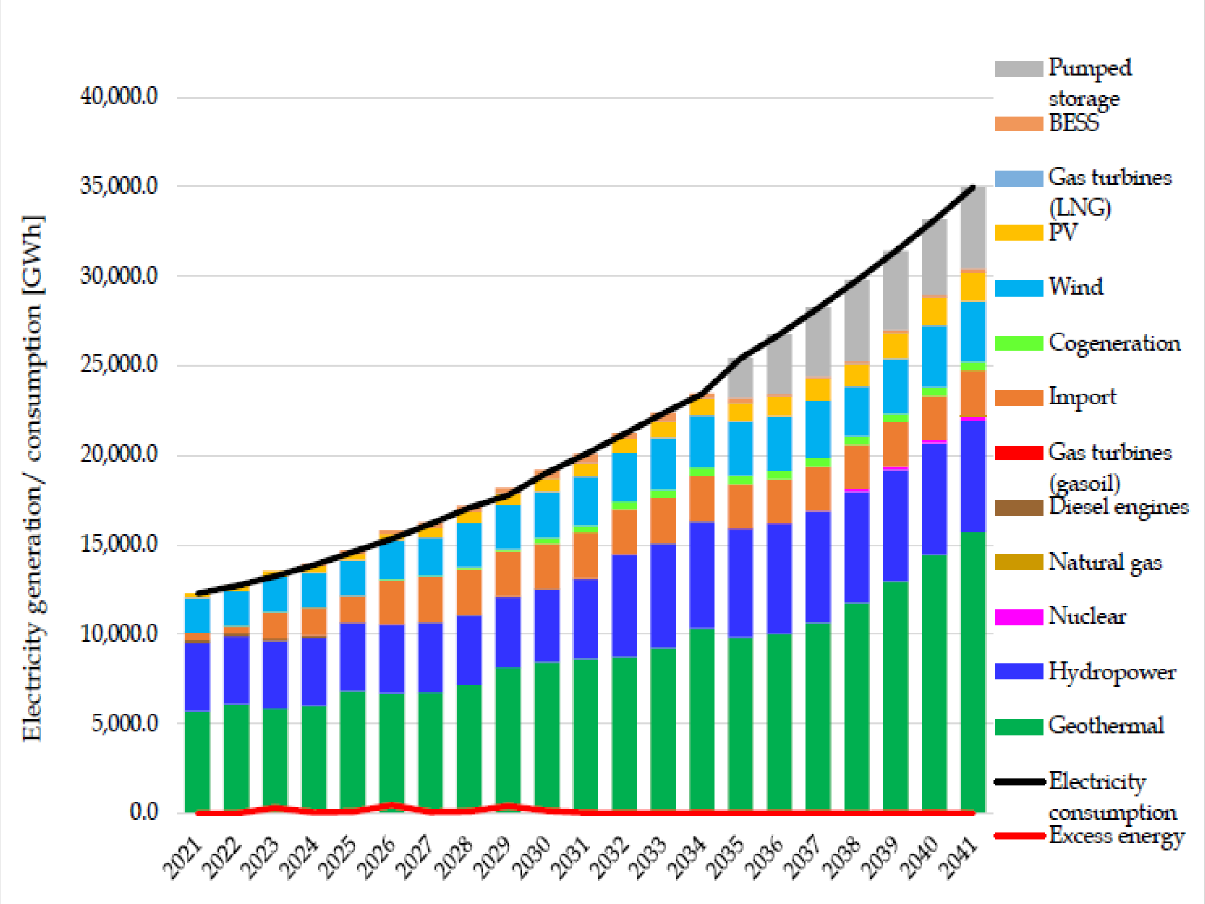


Figure 6: Generation expansion mix in 2022-2041 period using recent LIPS Model

Source: LCPDP report 2022-2041

Equally, generation planning will cover a period of 15 years from 2021-2035. The Previous LIPS XP/OP generation expansion model for 2022-2041 has been identified as the base case model for generation expansion planning. The model will be updated with a more recent data on generation planning, removing the subjectivity that may have arisen during the planning period.

The same data as above will be used to update the WASP IV model of 2013-2033 LCPDP. The model will be used to generate corresponding results that will be used for the comparative analysis. Future generation planning will involve:

Review and correction of the key assumptions – Some inputs and assumptions will be adjusted to reflect the true and more accurate position for an effective system. World best practice will also be applied to come up with these inputs. This will be based on the new market trends, renewable energy cost studies like IRENA.

Identification of committed projects – These are projects whose implementation is either started or their implementation schedule is firmed up either by a signed PPA or have reached financial close. In the future planning consideration and in order to plant the projects according to the demand forecast, some projects that have not achieved a big milestone will be staggered to allow for demand-supply balance.

Identification of candidate projects – Candidate projects are those projects that are flexible enough and are not committed. The model is free to choose from different technologies according to the set parameters and constraints. These will consider stability, system flexibility, reliability, reserves requirement, cost and intermittency. The process shall involve: Cost update; Projects screening; Simulation of Least cost generation expansion; Evaluation of potential expansion paths with regard to system criteria (reliability, reserve) and system costs (net present value); The simulations will be subject to the following constraints: Candidates expansion restrictions (“tunnels”); Reserve restrictions; Loss of load probabilities; Hourly dispatch for hourly load curves Simulations will be based on various technologies including Geothermal, Thermal, Coal, Nuclear, Hydro, Wind, solar and Imports. The study will seek to optimize the available resources under various identified constraints. Innovation will be applied to incorporate new technologies like pumped storage hydro power, Battery Energy Storage (BESS) among others that support renewable energy as well as energy efficiency.

3.2.3 Demand-Supply Balance

Grid balancing in power distribution has acquired a great relevance lately in ensuring that supply of electricity meets its demand. In more recent years this has become less anticipated as more renewable energy are being installed into the grid due to the intermittency nature of some of the renewable electricity generators.

A prudent power system is the one whose power supply is well balanced with the demand for it, at some predetermined reserve levels as the system may require. This means that the implementation of projects should be necessitated by the demand for power and the required reserve provisions to ensure a secure and stable power supply.

Electricity planning in Kenya has however been faced with the challenge of balancing the power system due to various reasons including preference of certain projects over others, lack of screening of projects, lack of prioritization and demand driven supply without looking at system optimization.

One great weakness with the WASP model is that it does not provide demand supply report as opposed to the LIPS XP/OP Model which highlights the system shortfalls and excesses as shown on the table below:

Table 6: 2015-2035 Demand Supply balance

	Unit	2015	2016	2019	2020	2022	2025	2028	2030	2033	2035
Firm system capacity	MW	2021	2012	2804	2843	3536	3725	3723	3633	3518	3269
Peak load											
Visio scenario	MW	1570	1770	2545	2845	3325	4431	5665	6833	8710	10219
Reference scenario	MW	1570	1679	2120	2259	2633	3282	4040	4732	5813	6683
EE scenario	MW	1570	1679	2032	2077	2279	2700	3221	3729	4497	5136
Low scenario	MW	1570	1669	2025	2116	2373	2769	3245	3618	4276	4788
Supply gap(firm capacity-peak load											
Visio scenario	MW	451	242	259	-2	211	-707	-1942	-3200	-5191	-6949
Reference scenario	MW	451	333	683	584	903	443	-317	-1099	-2295	-3413
EE scenario	MW	451	333	772	766	1257	1024	502	-96	-978	-1867
Low scenario	MW	451	342	778	727	1163	956	478	16	-758	-1519
Peak load plus reserve margin											
Visio scenario	MW	1840	2064	2932	3268	4051	5290	6672	7980	10082	11772
Reference scenario	MW	1840	1962	2457	2612	3276	4003	4852	5627	6838	7812
EE scenario	MW	1840	1962	2358	2408	2880	3351	3935	4504	5363	6079
Low scenario	MW	1840	1952	2350	2452	2984	3428	3962	4379	5116	5690
Supply gap(firm capacity-peak load plus reserve margin)											
Visio scenario	MW	180	-53	-128	-425	-515	-1565	-2948	-4347	-6563	-8503
Reference scenario	MW	180	49	347	231	260	-278	-1129	-1994	-3320	-4542
EE scenario	MW	180	49	446	435	656	373	-211	-870	-1845	-2810
Low scenario	MW	180	60	453	391	552	297	-238	-746	-1598	-2421

Source: LCPDP 2015-2035

For the WASP IV model, the analysis of demand and supply balance is undertaken manually and outside the model. This is a model weakness which is susceptible to errors and misrepresentation as opposed to LIPS XP/OP model of which the demand supply balance is a working sheet which balances the system as the sequence planting progresses.

3.3 Methodology

4.2.2 Models Description

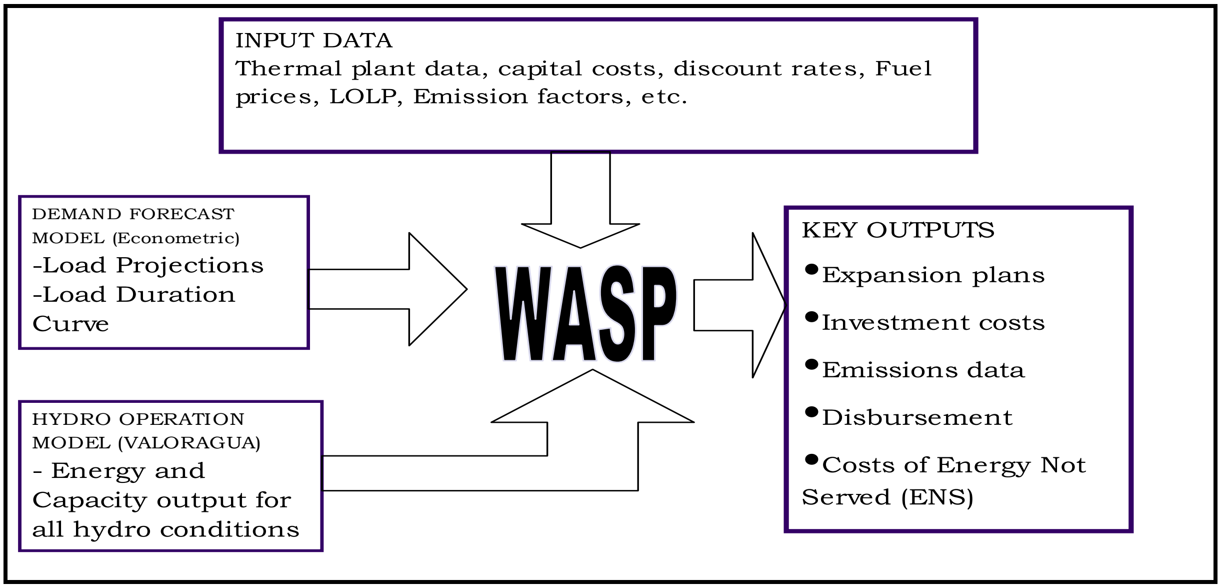
3.3.1.1 Wien Automated System Planning (WASP)

WASP is a cost reduction tool with the key objective of simulating the power expansion plan with the minimum possible cost in present value, for a given time period. The model uses probabilities instead of deterministic approach.

a) Conceptual Framework

Figure 3 shows a simplified flow chart of WASP-IV illustrating the flow of information from the various WASP modules and associated data files.

Figure 7: Conceptual Model for WASP-IV model



Source: WASP IV Manual

b) Model Specifications and variables

The WASP-IV simulations are aimed at optimizing electricity expansion plans for a power generating system over a given time period, mostly with thirty years lifespan, within some identified limitations. The optimal option is estimated in terms of the lowest or least discounted total costs.

Each possible series of power units that are added to the system upon meeting the limitations or constraints is assessed based on a cost function. The objective function which is the cost function is composed of variables as described in the table below:

Table 7: Variables Description

Symbol	Variable	Description
I	Capital investment costs	This includes cost of depreciable assets, machine & equipment, civil works, installation costs and development costs. This is a fixed cost
S	Residual value of investment costs	This is the estimated residual value of the plant at the end of the economic life of the plant. This is a constant
F	Fuel costs	Fuel costs associated with the running of a power plant. This is a variable cost
L	Fuel inventory costs	This is part of capital investment costs which is not depreciable. It includes fuel inventory, initial stock of spare parts etc. It is a variable cost
M	Operation & maintenance costs (Non-fuel)	These are costs associated with the running of the project. They include fixed costs like salaries, insurance and overhead costs. They also include variable costs like lubricants, chemicals, consumable, tools etc
O	Cost of the energy not served	This is the cost associated with um-met demand due to shortage of supply, connectivity issues or unwillingness to pay

Note: All the above variables are measured in US Dollars

Source: Own tabulation from IAEA WASP-IV model Manual

The **cost function for** WASP-IV can be expressed as follows:

$$B_j = \sum_{t=1}^{T} [\, \overline{I_{j,t}} - \overline{S_{j,t}} + \overline{F_{j,t}} + \overline{L_{j,t}} + \overline{M_{j,t}} + \overline{O_{j,t}} \,]$$

where:

- Bj is the objective function attached to the expansion plan j,
- t denotes time in years (1, 2, ..., T),
- T is the length of the study period (total number of years), and
- the bar over the symbols has the meaning of discounted values to a reference date at a given discount rate i.

The objective function is therefore to minimize B_j for all j.

Subject to: $(1+a_t)D_{tp} \geq P(K_{tp}) \geq (1+b_{t)}D_{tp}$, which states that the installed capacity in the critical period must lie between the given maximum and minimum reserve margins, a_t and b_t respectively, above the peak demand $D_{t,p}$ in the critical period p of the year.

The WASP analysis requires as a starting point the determination of alternative expansion policies for the power system. If $[K_t]$ is a vector containing the number of all generating units which are in operation in year t for a given expansion plan, then $[K_t]$ must satisfy the following relationship:

$$[\,K_t\,] = [\,K_{t-1}\,] + [\,A_t\,] - [\,R_t\,] + [\,U_t\,]$$

where:

$[A_t]$ = vector of committed additions of units in year t,

$[R_t]$ = vector of committed retirements of units in year t,

$[U_t]$ = vector of candidate generating units added to the system in year t.

$[A_t]$ and $[R_t]$ are known data while $[U_t]$ is the unknown variable to be determined, also called the system configuration.

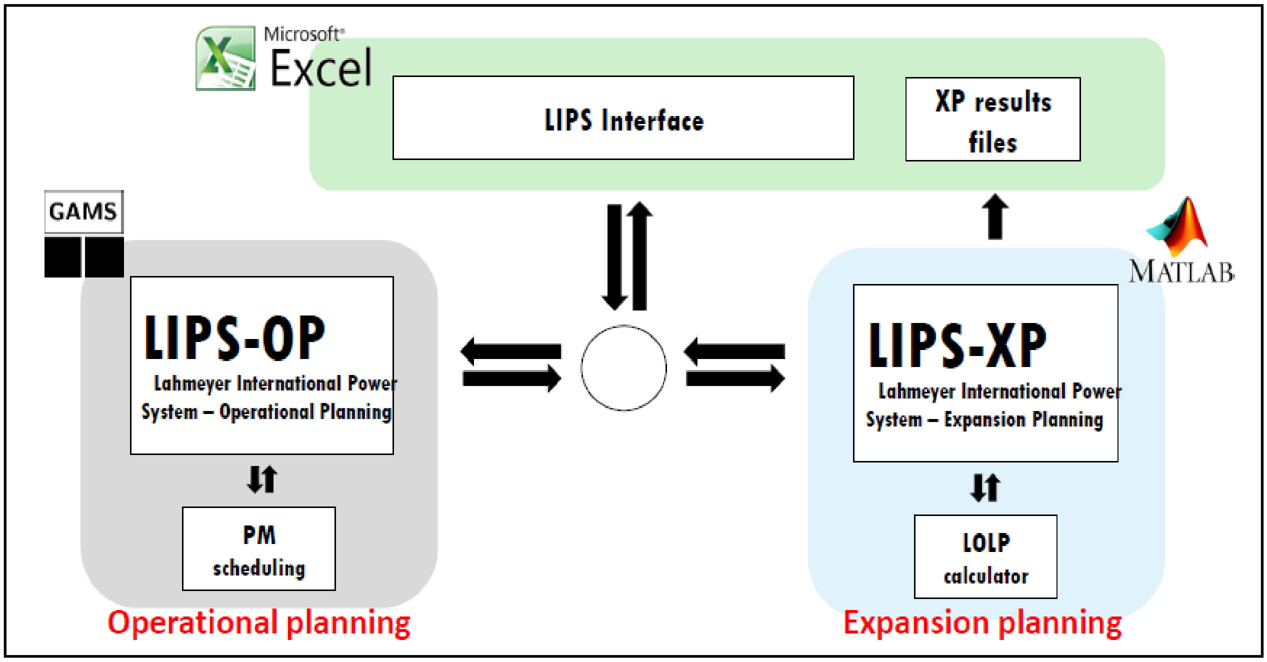
Defining the critical period (p) as the period of the year for which the difference between the corresponding available generating capacity and the peak demand has the smallest value, and if $P(K_{t,p})$ is the installed capacity of the system in the critical period of year t, following constraints should be met by every acceptable configuration:

3.3.1.1 LIPS XP/OP

a) Conceptual Framework

The conceptual framework will be as follows:

Figure 4:Conceptual Model for LIPS XP/OP



Source: LIPS XP/OP Installation Manual

b) Model Specifications and variables

This methodology is based on Fundamental Market Electricity Modelling Platform which seeks to optimize short run (operational dispatch and Unit Commitment) and long run (generation expansion) system costs. The approach will consist of: Simulation of Least cost generation expansion and Evaluation of potential expansion paths with regard to system criteria (reliability, reserve) and system costs (net present value).

Subject to:

- Candidates expansion restrictions (“tunnels”)
- Reserve restrictions
- Loss of load probabilities
- Hourly dispatch for hourly load curves

The model interfaces operational dispatch for committed units with generation expansion for optimization of costs. It aims at minimizing the short run and long run costs taking into consideration various constraints as highlighted above.

The variables description is as tabulated below:

Table 8: LIPS variables description

Symbol	Variable	Variable Description	Measure
CAPEXch	Annual CAPEX charge	This is the annual fixed charge that is associated with the investment cost	US Cents/KW
REHABch	Rehabilitation cost charge	It is the cost associated with major repairs of the power plant	US Cents/KW
FOPEX	Fixed OPEX	This is the annual fixed cost associated with operation and maintenance of the power plant	US Dollars
VOPEX	Variable OPEX	This is the variable cost for generating an additional KWh of energy at any given time	US Dollars
FC	Fuel cost	Fuel cost associated with operation of a power plant	US Dollars
UEC	Unserved energy cost	This is the cost associated with um-met demand due to shortage of supply, connectivity issues or unwillingness to pay	US Dollars

Source: Author tabulation from LIPS XP/OP model Manual

The objective function is:

$$TC = \sum_{y=1}^{ny} [DF_y \,.\, (\sum_{u=1}^{nu} CAPEXch_u + \sum_{u=1}^{nu} REHABch_u + \sum_{u=1}^{nu} FOPEX_u + \sum_{u=1}^{nu} VOPEX_{uy} + \sum_{u=1}^{nu} FC_{uy} + +UEC_y)]$$

Where;

TC	Total Cost
y	year
u	power plant units
nu	Number of power plant units
ny	Number of years
DF	Discount factor
CAPEXch	Annual CAPEX charge
REHABch	Rehabilitation cost charge
FOPEX	Fixed OPEX
VOPEX	Variable OPEX
FC	Fuel cost
UEC	Unserved energy cost

The total cost is the summation of capital cost for new generation capacity, rehabilitation cost of all existing units, fixed & variable cost, fuel cost and cost of unserved energy.

The objective function is therefore to minimize the Total Cost.

3.3.2 Comparing Model Results

The results comprise among other things a sequence of capacity expansion paths that give various projects implementation options at different costs. The aim is to choose the most optimal capacity expansion path at least cost. From the WASP IV and LIPS XP/OP model results, the reasonably best solutions are picked and compared, taking into consideration the total lifecycle costs (development, investment, operational and maintenance costs). The option with the least cost is the most optimal solution.

When comparing the effectiveness of different models, the following factors present very significant checkpoint for the comparison:

a) **Input assumptions** – A model is as good as the assumptions. The main assumptions to evaluate include technology cost & plant performance assumptions, fuel prices, constraints on specific technologies among others.

b) **Load forecast presentation –** The goal of planning is to have a system that is balanced, which means the supply should be adequate to meet demand in an efficient way. A planner needs to check the baseload demand, peak load demand, demand elasticity and energy efficiency against the planned supply for electricity.

c) **Tariff –** This is the ultimate goal for planning. A modeler will be more comfortable to present a model that gives competitive costs both at generation and end-use tariff. A model that results to higher tariff will be disadvantageous.

d) **Retirements –** It is important to evaluate which plants are proposed to retire at what time under different planning models.

e) **Country policies –** Countries policies may dictate which models to use in generation planning. For examples policies around the trading parameters, how to treat renewable resources, treatment of nuclear plant, policies on carbon emissions among others.

3.4 Data sources and types

The historical data used is based on modelling assumptions as well as results of WASP IV 2013-2033, LIPS XP/OP 2015-2035 and LIPS XP/OP 2022-2041 Master plans. For future forecasting and generation planning. Assumptions are reviewed based on current developments. Model Simulations are carried out to determine the future system growth.

3.4.1 Demand forecast data

The Following load curve data will be used in the simulation models

Table 9: Demand forecast from 2021 - 2035

Year	Vision	Growth rate	Vision	Growth rate	Reference	Growth rate	Low	Growth rate
2021	12416		12416		12416		12416	
2022	13527	8.95%	13444	8.27%	12891	3.82%	12738	2.59%
2023	14480	7.04%	14326	6.56%	13304	3.21%	13017	2.19%
2024	15526	7.23%	15235	6.35%	13760	3.43%	13311	2.26%
2025	16807	8.25%	16228	6.52%	14257	3.61%	13639	2.46%
2026	18078	7.56%	17296	6.58%	14780	3.67%	13992	2.59%

Year	Vision	Growth rate	Vision	Growth rate	Reference	Growth rate	Low	Growth rate
2027	19614	8.50%	18862	9.05%	15632	5.77%	14660	4.77%
2028	21392	9.07%	20485	8.61%	16538	5.79%	15377	4.89%
2029	23277	8.81%	22164	8.20%	17571	6.25%	16154	5.05%
2030	25840	11.01%	24273	9.51%	18680	6.32%	17048	5.54%
2031	28171	9.02%	26299	8.35%	19722	5.58%	17993	5.54%
2032	30715	9.03%	28502	8.38%	20877	5.85%	18902	5.05%
2033	33304	8.43%	30712	7.76%	22050	5.62%	19869	5.12%
2034	36114	8.44%	33150	7.94%	23301	5.68%	20899	5.18%
2035	39324	8.89%	35851	8.15%	24617	5.65%	21977	5.16%
Growth rate		8.59%		7.97%		5.22%		4.50%

Source: LCPDP 2022-2041 Annexes

3.4.2 Generation planning data

Data is sourced from Kenya Electricity Sector institutions including Energy and Petroleum Regulatory Authority (EPRA), Kenya Electricity Generation Company (KenGen), Kenya Power (KPLC) and Kenya Nuclear Power & Energy Agency (NuPEA). Other sources will include Kenya National Board of Statistics (KNBS), The World Bank, International Atomic Energy Agency, the U.S Economic Information Administration, IRENA among others.

CHAPTER FOUR: DATA ANALYSIS, FINDINGS AND DISCUSSION

4.0 Introduction

The primary goal of this study was to assess the accuracy/reliability of different Kenya's Electricity Development Plans in order to have an optimized power system that can support the economic development. More specifically, the study sought to compare two generation plans between: the WASP model (which is a plan that has been used to focused different aspects of electricity for the period 2013-2033) and the LIPS XP/OP model (for plan 2015-2035) to identify any gaps that may exist between the two; identify generation projects (both committed and candidates) under various technologies taking into consideration institutional plans and system growth requirement, optimize the generation capacity expansion by running WASP and LIPS XP/OP taking note of the demand forecast in order to achieve demand-supply balance and Compare and contrast results for a more optimal solution.

An examination of the data obtained and findings of the study are presented in this chapter. Data analysis was carried out in three stages: first, the WASP model focus output, LIPS XP/OP model focus output and Actual observed values form the World Development Indicator on various aspects of the plans were cleaned, merged and coded to construct the variables of interest; second, STATA version 14 was used for statistical analysis; and finally, the results were reported and discussed. Simple descriptive analysis involving mean difference and their significance level are used to make inferences on various variables of interest. We begin with the descriptive statistics which explores the data that is used from the perspective of the number of observations, mean, standard deviation, minimum and maximum values.

4.1 Descriptive statistics

Table 9 shows the descriptive statistics of the variables used in this study. From the findings, the actual observed net electricity generation capacity of Kenya between 2015 and 2021 was averagely 10,053.16GWh with a large standard deviation of 1,011.617GWh. The large standard deviation can be loosely interpreted as annual fluctuations resulting from both internal and external shocks such as system downtime or climatic/weather variability's. The minimum and maximum actual generation capacity was found to be 8,703.44GWh and 11,576.55GWh respectively. In the same period (2015-2021) the WASP model had predicted a net annual electricity generation capacity of 91,453.75GWh with an annual standard deviation of 33,557.02GWh based on its underlying assumptions. Equally, the result reveals that LIPS XP/OP model, the annual average net electricity generation was about 27,462.8GWh with a standard deviation of 3,352.853GWh.

For annual electricity consumption, the result from the actual observed values indicate a consumption of 78,422.97GWh with a standard deviation of about 8,665.985GWh. The actual annual low peak and high peak were found to be 6,5314GWh and 9,2665.54GWh respectively. In the same period, the mean annual electricity consumption focused for the WASP and LIPS XP/OP models were 14,5202.3GWh and 28,265.08GWh respectfully.

At individual technology level, the findings reveal that between 2015 and 2035, the mean annual electricity generation capacities for geothermal, hydropower, Diesel engines, Imports, Cogeneration and wind were 2,235.048MWh, 553.0325MWh, 400.597MWh, 238.6964MWh, 10.39924MWh and 117.306MWh respectively. This implies that the two prediction models (WASP and LIPS XP/OP) assign more weight to geothermal technology as compared to other technology to supply electricity in the future.

Consumption prediction for individual technologies reveals that between 2015 and 2035, the mean annual electricity consumption for geothermal, hydropower, Diesel engines, Imports, Cogeneration, wind and PV were 1,034.921 MWh, 162.8214 MWh, 1379.367 megawatt hours, 52.31145MWh, 1325.019MWh and 351.2287 MWh respectively.

At individual technologies level, the study findings reveal that investment and rehabilitation annual mean costs between 2015 and 2035 for geothermal, hydropower, Diesel engines, Imports, Cogeneration, wind and PV were USD 367.8802 million, USD 182.2918 million, USD 112.2391 million, USD 32.1876 million, USD 17.80155 million, USD 112.087 million and USD 46.09093 million and USD 351.2287 million respectively.

On average, the result revealed that geothermal technology required USD101.4991 million as fixed operation and maintenance cost with a further USD 73.32 million as variable operation and maintenance annually. Hydropower technology was predicted to require USD 25.03673 million as fixed operation and maintenance cost with a further USD 2.664936 million as variable operation and maintenance annually. Further, Diesel engines was predicted to require USD 18.32878 million as fixed operation and maintenance cost with a further USD 1.242387 million as variable operation and maintenance annually. The annual fixed and variable operation and maintenance for import technology was found to be USD 5.019738 million and USD 68.29752 million respectively. Equally, the annual fixed and variable operation and maintenance for Cogeneration technology was found to be USD 5.10017 million and USD 1.291995 million respectively. Additionally, it’s established that wind technology had only the annual fixed operation and maintenance of about USD 32.10314million while the PV technology had USD 8.951473million. The two technologies had no annual variable operation and maintenance costs.

Table 10: Descriptive statistics

Variable	**obs**	**Mean**	**Std**	**Min**	**Max**
Net generation capacity (ACTUAL)	8	10053.16	1011.617	8703.44	11576.55
Net generation capacity (WASP)	8	91453.75	33557.02	50870	146800
Net generation capacity (LIPS)	8	27462.8	3352.853	22818.58	31970.54
Net Consumption (ACTUAL)	8	78422.97	8665.985	65314	92665.54
Net Consumption (WASP)	8	145202.3	17541.59	122973.6	170871.2
Net Consumption (LIPS)	8	28265.08	18045.76	9440	56331.67
Generation capacity					
Geothermal	42	2235.048	2041.555	114	7305
Hydropower	42	553.0325	229.2427	280.1211	1125.213
Diesel engines	42	400.597	203.625	83	814.5153
Import	42	238.6964	140.7691	28.51191	400
Cogeneration	42	10.39924	14.40626	.064	54.72
Wind	42	117.306	45.59201	43.27024	202.75
Consumption					
Geothermal	42	1034.921	294.6895	662.8369	1724.3
Diesel engines	42	162.8214	105.3447	11.24324	343.2863
Import	42	1379.367	879.0474	223.3405	2965.653
Cogeneration	42	52.31145	80.5269	8.76	328.5
Wind	42	1325.019	706.4116	16.03098	2823.409
PV	42	351.2287	333.0093	8.962997	1212.93
Investment and rehabilitation costs					
Geothermal	42	367.8802	86.99633	252.4406	636.536

Variable	**obs**	**Mean**	**Std**	**Min**	**Max**
Hydropower	42	182.2918	90.30352	53.69959	427.2579
Diesel engines	42	112.2391	63.94959	20.18266	271.1738
Import	42	32.1876	21.61707	11.41624	68.32391
Cogeneration	42	17.80155	20.3291	.2077705	65.55059
Wind	42	112.087	51.16141	17.36785	218.4798
PV	42	46.09093	32.35803	2.099871	122.0317
Operations and maintenance cost (fixed)					
Geothermal	42	101.4991	28.63098	46.67138	156.1892
Hydropower	42	25.03673	3.56161	20.95927	34.7039
Diesel engines	42	18.32878	5.999235	2.6145	29.61829
Import	42	5.019738	3.446484	.1006667	10.16
Cogeneration	42	5.10017	7.709727	.1192665	24.87931
Wind	42	32.10314	11.5819	13.17146	61.7171
PV	42	8.951473	5.683833	.9592665	19.04776
Operations and maintenance cost (variable)					
Geothermal	42	73.31721	41.20553	-23.2236	135.2392
Hydropower	42	2.664936	1.682755	.191203	7.013472
Diesel engines	42	1.242387	1.551372	.0989405	5.794721
Import	42	68.29752	66.86916	3.105867	179.079
Cogeneration	42	1.291995	1.826023	.02446	7.240849

4.2 Analysis of Generation Capacity

Analysis of this study is done per objectives. Therefore, in the proceeding subsection, analysis of the first objective, which was to compare two generation plans: WASP model (2013-2033) and LIPS XP/OP (for plan 2015-2035) is done through computing the mean difference between different dimensions such as generation capacity, consumption forecast for each technology, investment and rehabilitation projections, fixed and variable operational and maintenance costs. However, we first compare the projections of the two models (WASP model and LIPS XP/OP model) with the actual observed values in the last eight years (2015-2021) in effort to compare which of the model has an accurate predictability of the actual generation capacity, consumption and costs.

4.2.1 Generation capacity between WASP Model and ACTUAL Values

To compare the generation capacity between WASP model and LIPS XP/OP model, first, the study computed the mean difference between what the individual models had focused and the Actual observed values for a period of eight years (2015-2021). Large and significant mean difference between the individual model and the actual observed values is interpreted as "the model has a weak focusing power" while small and significant mean difference or insignificant mean difference was interpreted as an efficient and reliable model focus. The results of the analysis are shown in table 11 below.

Table 11: Generation capacity between WASP predicted values and Actual value

	Obs	Mean	Std error	Std dev
Actual	8	10053.16	357.6607	1011.617
WASP	8	91453.75	11864.2	33557.02
Combined	16	50753.45	11971.13	47884.52
diff = mean (ACTUAL) – mean (WASP)		**-81400.59*** **	11869.59	
Ho: diff = 0	t = -6.8579	df = 14	**Pr(T > t) = 0.0000**	

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

The findings from Table 11 indicate that, on average, the mean annual actual electricity generation capacity of Kenya is about 10053.16 MW with a high standard deviation of about 357.66 MW, which can be interpreted as generation shocks resulting from both external and internal unforeseen events such as climate change and weather variability. Further, the annual mean focus for WASP electricity generation was about 91453.75 MW with a standard deviation of 11864.2 MW.

However, a significant mean difference (t = -6.8579; Pr (T >t) =0.0000) between the Actual observed values and the WASP model focus led us to reject the null hypothesis of no difference between the Actual electricity generation and whet WASP had predicted and conclude that there is a significant deviation. That is, the study findings of an annual mean difference of -81400.59 implies that the WASP model overestimate the country's annual electricity generation by about 81400.59 MW. There is therefore a need to redefine some of the assumptions that the WASP model relies on in the electricity generation focus to make it more reliable in giving a true picture of the electricity generation.

4.2.2 Generation capacity between ACTUAL Values and LIPS XP/OP model

In this subsection, the study compares Actual observed values of Kenya's electricity generation capacity and those predicted by the LIPS XP/OP model for a period of eight years (2015-2021). The findings are presented in Table 12.

Table 12: Generation capacity between LIPS XP/OP predicted values and Actual value

	Obs	Mean	Std error	Std dev
Actual	8	10053.16	357.6607	1011.617
LIPS XP/OP	8	27462.8	1185.413	3352.853
Combined	16	18757.98	2325.795	9303.18
diff = mean(ACTUAL) - mean(LIPS)		**-17409.64*** **	1238.194	
Ho: diff = 0	t = -14.0605	df = 14	**Pr(T > t) =**	**0.0000**

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Results in Table 12 reveal that the annual average predicted electricity generation through the LIPS XP/OP model was about 2,7462.8MW with a standard deviation of about 1,185.413MW. Further, comparing the mean annual electricity generation between the predicted values of the LIPS XP/OP model, the study results reveal that the mean difference was 17,409.64 MW which was also statistically significant ($p < 0.05$). This result implies that the mean annual predicted values of the LIPS XP/OP model was statistically different from the actual observed values of electricity generation. Intuitively, the LIPS XP/OP model's predicted values cannot be relied upon in focusing for the electricity generation capacity. If fact, we found that the LIPS XP/OP model over estimate future electricity generation capacity. There is therefore a need to review some of the assumptions that the model is based on in prediction of future electricity generation in the country.

4.2.3 Generation capacity between WASP and LIPS XP/OP model

In this subsection, the study compares WASP annual predicted electricity generation capacity and those predicted by the LIPS XP/OP model for a period of eight years (2015-2021). Table 13 presents the findings.

Table 13: Comparing electricity generation prediction between WASP and LIPS XP/OP

	Obs	Mean	Std error	Std dev
WASP	8	91453.75	11864.2	33557.02
LIPS XP/OP	8	27462.8	1185.413	3352.853
Combined	16	59458.28	10070.7	40282.81
diff = mean (LIPS) – mean (WASP)		**-63990.95*****	11923.27	
Ho: diff = 0	t = -5.3669	df = 14	**Pr(T > t)** = **0.0000**	

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Results in Table 13 reveal that although both models overestimate the electricity generation capacity for Kenya in comparison with the Actual observed values, the WASP model estimations are larger than the LIPS XP/OP model's overestimation by an average annual mean of 63,990.95 MW (which the study finding found to be statistically significant (t = -5.3669, p<0.05)). The implication of the findings, therefore can mean that if the assumptions of the LIPS XP/OP model re-evaluated, its future prediction of the country's electricity generation capacity can be accurate and reliable than the WASP model. To further understand how each model performs in the specific electricity generation capacity, in the next subsection, we compared the electricity mean differences between LIPS XP/OP model and the WASP model between 2021 and 2035.

4.2.4 Generation capacity between WASP and LIPS XP/OP model at specific model

In this subsection, we compared the focus for LIPS XP/OP model and the WASP model between 2021 and 2035 on specific technologies such as Geothermal, wind and hydropower. Table 14 presents the table findings.

Table 14: Comparing specific technology's electricity generation capacities between WASP and LIPS XP/OP

	Obs	WASP	LIPS XP/OP	diff = mean(LIPS) - mean(WASP)	Significance
Geothermal	21	3457.714	1012.382	**-2445.333 *****	t = -4.8200 df = 40 **Pr(|T| > |t|) = 0.0000**
Hydropower	21	375.6379	730.4271	**354.7892*****	t = 7.9668 df = 40 **Pr(|T| > |t|) = 0.0000**
Diesel engines	21	262.3519	538.8422	**276.4903*****	t = 5.9819 df = 40 **Pr(|T| > |t|) = 0.0000**
Import	21	222.0952	255.2976	**33.20238**	t = 0.7603 df = 40 **Pr(|T| > |t|) = 0.4515**
Cogeneration	21	7.525714	13.27276	**5.747048**	t = 1.3037 df = 40 **Pr(|T| > |t|) = 0.1998**
Wind	21	117.306	117.306	**-3.63x10^{-7e}**	t = -0.0000 df = 40 **Pr(|T| > |t|) = 1.0000**

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Findings in Table 14 reveal that the two models under study (WASP and LIPS XP/OP) have no significant difference in their focus of electricity generation in Import technologies (t = 0.7603; p > 0.05), cogeneration technology (t = 1.3037; p > 0.05) and wind technology (t = -0.0000; p > 0.05). However, the study found a significant difference in both model's predictions of electricity generation in geothermal technologies (t = -4.8200; p < 0.05), Hydropower technology (t = 7.9660; p < 0.05) and diesel engine technology (t = 5.9819; p < 0.05). The WASP model was found to overestimate the geothermal technology generation capacity while LIPS XP/OP model overestimated hydropower and Diesel engine technology generation capacity.

4.3 Consumption of individual technology electricity in Kenya

4.3.1 Consumption between WASP and LIPS XP/OP model at specific model

In this subsection, the study compares the consumption predictions of different technologies between the WASP and LIPS XP/OP. Table 15 presents the result.

Table 15: Comparing specific technology's consumption between WASP and LIPS XP/OP model at specific model

	Obs	**WASP**	**LIPS XP/OP**	**diff = mean(LIPS) - mean(WASP)**	**Significance**
Geothermal	21	1031.768	1038.074	6.305952	t = 0.0685 df = 40 Pr(|T| > |t|) = 0.9457
Hydropower	21	4246.742	4196.326	-50.41554	t = 0.7830 df = 40 Pr(|T| > |t|) = 0.7830
Diesel engines	21	164.8415	160.8012	**-4.040265***	t = -0.1228 df = 40 **Pr(|T| > |t|) = 0.9029**
Import	21	1120.265	1638.469	**518.2034***	t = 1.9768 df = 40 **Pr(|T| > |t|) = 0.0550**
Cogeneration	21	30.955	73.66789	**42.71288***	t = 1.3037 df = 40 **Pr(|T| > |t|) = 0.0857**
Wind	21	1016.485	1633.552	**617.0669*****	t = 3.1169 df = 40 **Pr(|T| > |t|) = 0.0034**
PV	21	185.9848	516.4726	**330.4878*****	t = 3.6732 df = 40 **Pr(|T| > |t|) = 0.0007**

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

From the result in Table 15, the findings reveal that the two models had no significance in their prediction of geothermal technology (t = 0.0685; P > 0.05) and hydropower technology (t = 0.7830; P > 0.05). However, the study reveals that there was a significance difference in prediction of diesel engine technology (t = -0.1228; P < 0.05), import technology (t = 1.9768; P< 0.05), cogeneration technology (t = 1.3037; P < 0.05), wind technology (t = 3.1169; P < 0.05) and PV technology (t = 3.6732; P < 0.05). The WASP model was found to overestimate diesel engine technology consumption while LIPS XP/OP estimated Import technology consumption; cogeneration technology consumption, wind technology consumption and PV technology consumption.

4.4 Investment and rehabilitation costs

In this subsection, the study compares the mean annual investment and rehabilitation costs for different technologies between the WASP and LIPS XP/OP between 2015 and 2035. Table 16 presents the result.

Table 16: Investment and rehabilitation costs between the WASP and LIPS XP/OP

	Obs	**WASP**	**LIPS XP/OP**	**diff = mean(LIPS) - mean(WASP)**	**Significance**
Geothermal	21	316.9946	418.7658	101.7712***	t = 4.6458 df = 40 Pr(|T| > |t|) = 0.0000
Hydropower	21	132.338	232.2457	99.90769***	t = 4.2736 df = 40 Pr(|T| > |t|) = 0.0001
Diesel engines	21	107.0065	117.4717	10.46514	t = 0.5256 df = 40 Pr(|T| > |t|) = 0.6021
Import	21	18.57935	45.79584	27.21649***	t = 5.2283 df = 40 Pr(|T| > |t|) = 0.0000
Cogeneration	21	24.89687	10.70624	-14.19063**	t = -2.3881 df = 40

	Obs	**WASP**	**LIPS XP/OP**	**diff = mean(LIPS) - mean(WASP)**	**Significance**
					Pr(|T| > |t|) = 0.0217
Wind	21	96.30044	127.8735	31.57304**	t = 2.0792 df = 40 Pr(|T| > |t|) = 0.0441
PV	21	35.94793	56.23392	20.28599**	t = 2.1158 df = 40 Pr(|T| > |t|) = 0.0406

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Results from Table 16 reveal that the two models have significantly different estimates for investment and rehabilitation costs with the LIPS XP/OP model overstating geothermal technology, hydropower technology, diesel engine technology, import technology, wind technology and PV technology. WASP only overstated cogeneration technology. This implication of this is that the WASP model yield the minimum costs associated with investment and rehabilitation in most of the electricity generation in Kenya except for the cogeneration technology.

4.5 Operation and maintenance (fixed cost)

Further, we analyzed the fixed operational and maintenance costs predicted by the WASP and LIPS XP/OP between 2015 and 2035. Table 17 presents the result.

Table 17: Operation and maintenance (fixed costs) between WASP and LIPS XP/OP (2015 -2035).

	Obs	WASP	LIPS XP/OP	diff = mean(LIPS) - mean(WASP)	Significance
Geothermal	21	101.4303	101.568	101.4991	t = 0.0154 df = 40 Pr(|T| > |t|) = 0.9878
Hydropower	21	25.154	24.91946	-.2345369	t = -0.2109 df = 40 Pr(|T| > |t|) = 0.8341

Diesel engines	21	18.84945	17.8081	-1.041347	t = -0.5577 df = 40 Pr(|T| > |t|) = 0.5801
Import	21	3.572952	6.466524	2.893571***	t = 2.9684 df = 40 Pr(|T| > |t|) = 0.0050
Cogeneration	21	6.180755	4.019585	-2.16117	t = -0.9064 df = 40 Pr(|T| > |t|) = 0.3702
Wind	21	28.49836	35.70793	7.209575**	t = 2.0992 df = 40 Pr(|T| > |t|) = 0.0422
PV	21	9.962789	7.940156	-2.022633	t = -1.1579 df = 40 Pr(|T| > |t|) = 0.2538

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The results in Table 17 indicate that the two models did not have any significant prediction on operational and maintenance fixed costs in most of the technologies except in imports technology (t = 2.9684; P < 0.05) and wind technology (t = 2.0992; P < 0.5). In the two cases, the LIPS XP/OP was found to overestimate the operational and maintenance fixed costs

4.6 Operation and maintenance (variables costs)

Further, we analyzed the variable operational and maintenance costs predicted by the WASP and LIPS XP/OP between 2015 and 2035. Table 18 presents the result.

Table 18: Operation and Maintenance variable cost

	Obs	WASP	LIPS XP/OP	diff = mean(LIPS) - mean(WASP)	Significance
Geothermal	21	56.00781	90.62661	34.61881***	t = 2.9709 df = 40 Pr(|T| > |t|) = 0.0050
Hydropower	21	3.361183	1.968689	-1.392494***	t = -2.9166 df = 40 Pr(|T| > |t|) = 0.0058
Diesel engines	21	.4799189	2.004855	1.524936***	t = 3.6266 df = 40

					Pr(|T| > |t|) = 0.0008
Import	21	33.39357	103.2015	69.8079 ***	t = 3.9353 df = 40 Pr(|T| > |t|) = 0.0003
Cogeneration	21	1.590042	.9939486	-.5960934	t = -1.0594 df = 40 Pr(|T| > |t|) = 0.2958

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Findings from Table 18 reveal that the two model's prediction on variable operational and maintenance cost statistically significantly differed in geothermal technology ($t = 2.9709$; $p < 0.05$), hydropower technology ($t= -2.9166$; $p < 0.05$), Diesel engine technology ($t = 3.6266$; $p < 0.05$) and Import technology ($t = 3.9353$; $p < 0.05$). However, the LIPS XP/OP was found to overstate most of the technologies with WASP only overstating hydropower. Intuitively, this implies that the WASP model was yielding the least variable operational and maintenance cost over the LIPS XP/OP between the periods under study.

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter covers the study summary, the conclusions made by study and their policy implications and a suggestion for an area of further research.

5.1 Summary

The main objective of this study was to assess the accuracy/reliability of different Kenya's Electricity Development Plans in order to have an optimized power system that can support the economic development. More specifically, the study sought to compare two generation plans between: the WASP model (which is a plan that has been used to focused different aspects of electricity for the period 2013-2033) and the LIPS XP/OP model (for plan 2015-2035) to identify any gaps that may exist between the two; identify generation projects (both committed and candidates) under various technologies taking into consideration institutional plans and system growth requirement, Optimize the generation capacity expansion by running WASP and LIPS XP/OP taking note of the demand forecast in order to achieve demand-supply balance and Compare and contrast results for a more optimal solution.

To achieve these specific objectives, data on Actual observed values were compared with predicted values of the two plans (WASP and LIPS XP/OP) in those years they have been operational through computing the mean difference and testing whether it's significant or not. Equally, the two models were compared in terms of which predicts the least costs (fixed or variable and investment and rehabilitations). In each case, the mean difference is computed and tested whether it is significant or not. Our comparison is based on the fact that large and significant mean difference between the individual model and the actual observed values is interpreted as “the model has a weak focusing power” while small and significant mean difference or insignificant mean difference was interpreted as an efficient and reliable model focus.

The finding reveals that, in the generation capacity, although both models overestimates the electricity generation capacity for Kenya in comparison with the Actual observed values, the WASP model estimations are larger than the LIPS XP/OP model’s overestimation by an average annual mean of 63990.95 MW. The implication of the findings, therefore can mean that if the assumptions of the LIPS XP/OP model can be re-evaluated, its future prediction of the country’s electricity generation capacity can be accurate and reliable than the WASP model. However, at specific technology level, the study revealed that, the WASP model was found to overestimate the geothermal technology generation capacity while LIPS XP/OP model overestimated hydropower and Diesel engine technology generation capacity, implying that the WASP model could be relied on in some specific technologies if its assumptions were re-evaluated.

At consumption level, the study findings revealed that the two models had no significance in their prediction of geothermal technology and hydropower technology, but significantly differ in prediction of diesel engine technology, import technology, cogeneration technology, wind technology and PV technology. The WASP model was found to overestimate diesel engine technology consumption while LIPS XP/OP estimated Import technology consumption; cogeneration technology consumption, wind technology consumption and PV technology consumption. Intuitively, each of these models will be efficient if its assumption are re-evaluated.

On investment and rehabilitation costs, the result revealed that the two models have significantly different estimates with the LIPS XP/OP model overstating most of the technologies (geothermal technology, hydropower technology, diesel engine technology, import technology, wind technology and PV technology) while the WASP only overstated cogeneration technology. This implication of this is that the WASP model yields the minimum costs associated with investment and rehabilitation in most of the electricity generation in Kenya except for the cogeneration technology.

For operational and maintenance costs, the result shows that the two models did not have any significant prediction on operational and maintenance fixed costs in most of the technologies except in imports technology and wind technology where the LIPS XP/OP model was found to overestimate the costs. Further, the revealed that the two model's prediction on variable operational and maintenance cost statistically significantly differed in geothermal technology, hydropower technology, Diesel engine technology and Import technology with the LIPS XP/OP found to overstate most of the technologies while WASP only overstating hydropower. Intuitively, this implies that the WASP model was yielding the least variable operational and maintenance cost over the LIPS XP/OP between the periods under study.

5.2 Conclusion and Policy Implications

Conclusively, we found that the two models were not accurate in predicting the country's electricity generation between 2015 and 2021 as they all overstated the production from the actual observed values. However, the LIPS XP/OP model has a lower overstated mean than the WASP Model. At individual technology level, the WASP model was found to overestimate the geothermal technology generation capacity while LIPS XP/OP model overestimated hydropower and Diesel engine technology generation capacity, implying that the WASP model could be relied on in some specific technologies if its assumptions were re-evaluated. For consumption, the study concludes that two models had no significance in their prediction of geothermal technology and hydropower technology, but significantly differ in prediction of diesel engine technology, import technology, cogeneration technology, wind technology and PV technology with WASP model was found to overestimate diesel engine technology consumption while LIPS XP/OP estimated Import technology consumption; cogeneration technology consumption, wind technology consumption and PV technology consumption. Finally, LIPS XP/OP model performed dismally in all costs (investment and rehabilitation, fixed and variable operational and maintenance costs) as WASP predicted least cost in most scenarios.

We thus recommend that each of the models be used where it is more accurate and reliable in predicting the true focused values of electricity in Kenya, for instance

1. With some re-adjustments of the assumptions of LIPS XP/OP model, the generation capacity of electricity in Kenyan can be predicted preciously as this model was found to deviate less from the actual observed values than the WASP model.

2. The WASP model was found to predict the least cost (both fixed and variable O&M costs as well as the investment and rehabilitation). We thus recommend that the assumptions in which the WASP model is based should be re-evaluated to capture the reality in predicting various costs of electricity in the country.

3. For consumption, either of the model can be used to predict future trends as there was limited mean difference between the two models.

5.3 Suggestions for Further Research

Since this area of research has not, to the best of our knowledge, been researched before, we suggest that there is need to further research in comparing both the LIPS XP/OP model and WASP model, first using a longer period of study (and not the eight years were able to obtain the actual values and the predicted values) and second, by using other key variables such as emissions, which our study could not obtain enough data.

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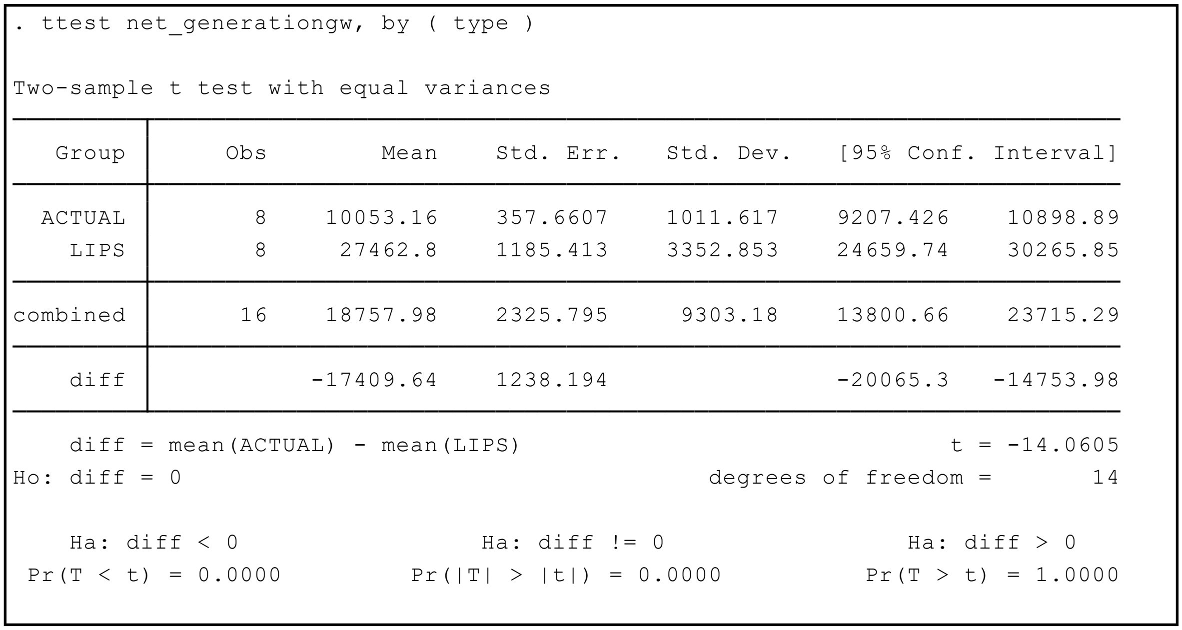
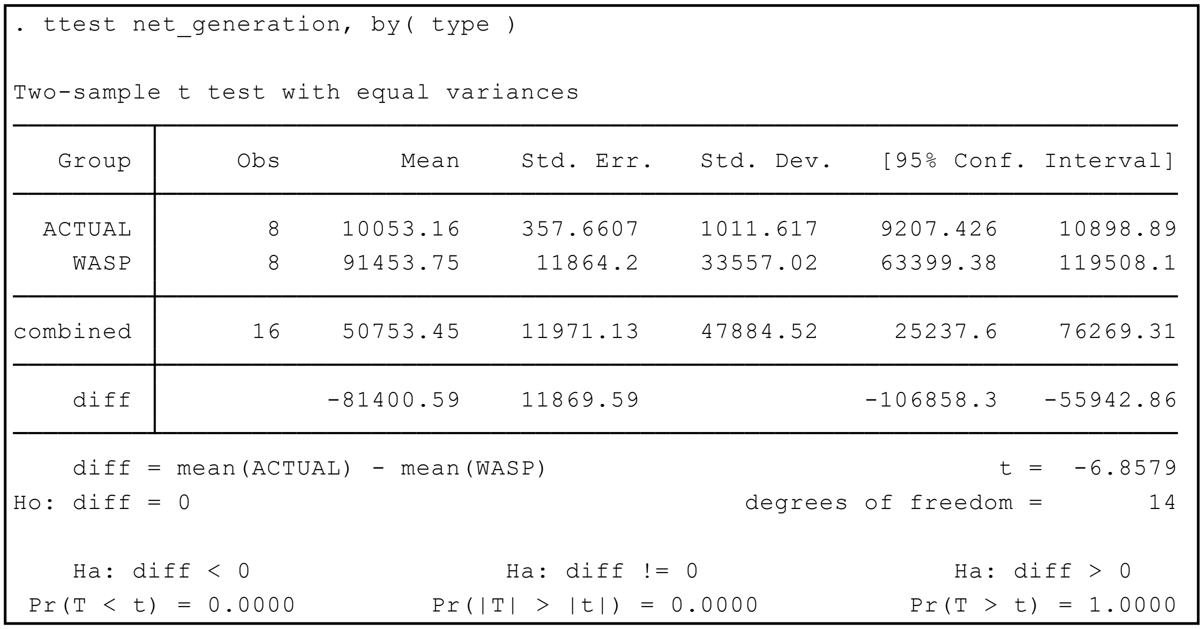
APPENDICES

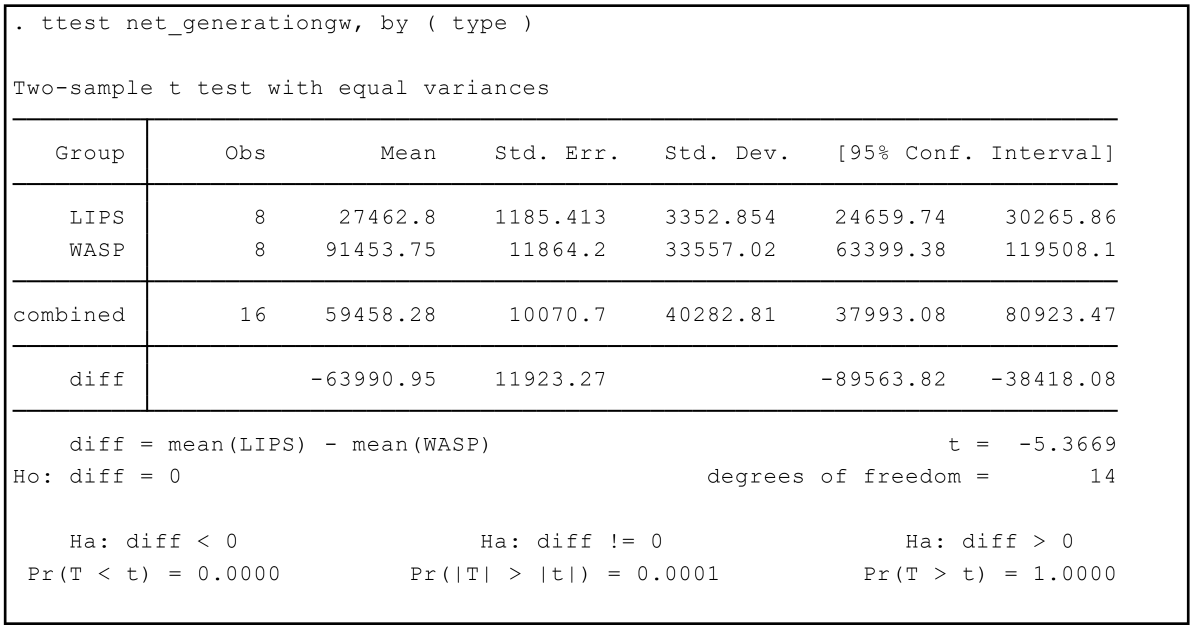
Generation capacity



```
. ttest net_generationgw, by ( type )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
  ACTUAL |       8    10053.16    357.6607    1011.617    9207.426    10898.89
    LIPS |       8     27462.8    1185.413    3352.853    24659.74    30265.85
---------+--------------------------------------------------------------------
combined |      16    18757.98    2325.795     9303.18    13800.66    23715.29
---------+--------------------------------------------------------------------
    diff |           -17409.64    1238.194                -20065.3   -14753.98
------------------------------------------------------------------------------
    diff = mean(ACTUAL) - mean(LIPS)                              t = -14.0605
Ho: diff = 0                                     degrees of freedom =       14

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```



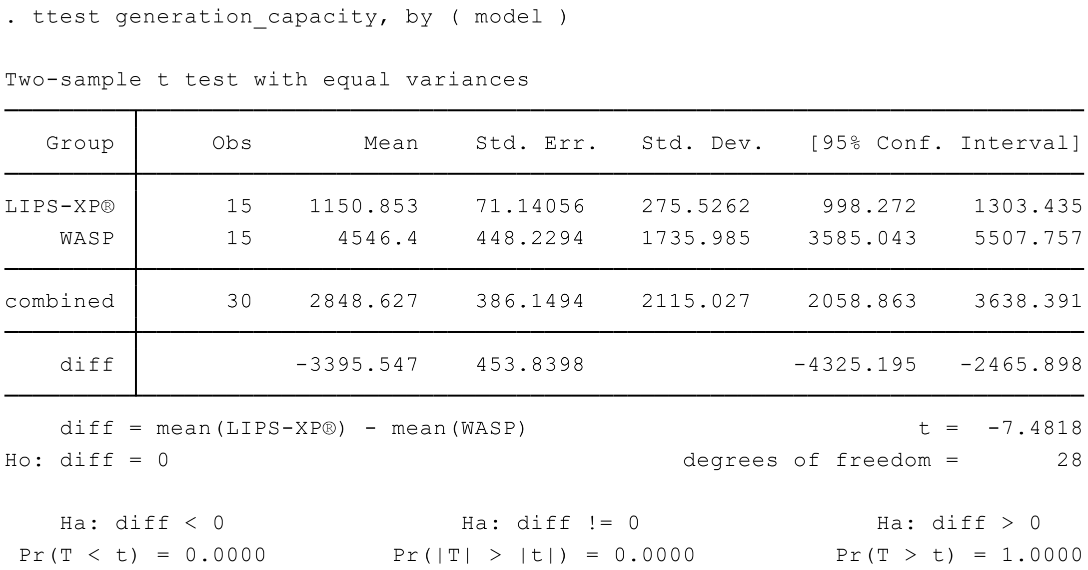
```
. ttest net_generation, by( type )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
  ACTUAL |       8    10053.16    357.6607    1011.617    9207.426    10898.89
    WASP |       8    91453.75     11864.2    33557.02    63399.38    119508.1
---------+--------------------------------------------------------------------
combined |      16    50753.45    11971.13    47884.52     25237.6    76269.31
---------+--------------------------------------------------------------------
    diff |           -81400.59    11869.59               -106858.3   -55942.86
------------------------------------------------------------------------------
    diff = mean(ACTUAL) - mean(WASP)                              t =  -6.8579
Ho: diff = 0                                     degrees of freedom =       14

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```



```
. ttest net_generationgw, by ( type )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
    LIPS |       8     27462.8    1185.413    3352.854    24659.74    30265.86
    WASP |       8    91453.75     11864.2    33557.02    63399.38    119508.1
---------+--------------------------------------------------------------------
combined |      16    59458.28     10070.7    40282.81    37993.08    80923.47
---------+--------------------------------------------------------------------
    diff |           -63990.95    11923.27               -89563.82   -38418.08
------------------------------------------------------------------------------
    diff = mean(LIPS) - mean(WASP)                                t =  -5.3669
Ho: diff = 0                                     degrees of freedom =       14

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0001          Pr(T > t) = 1.0000
```

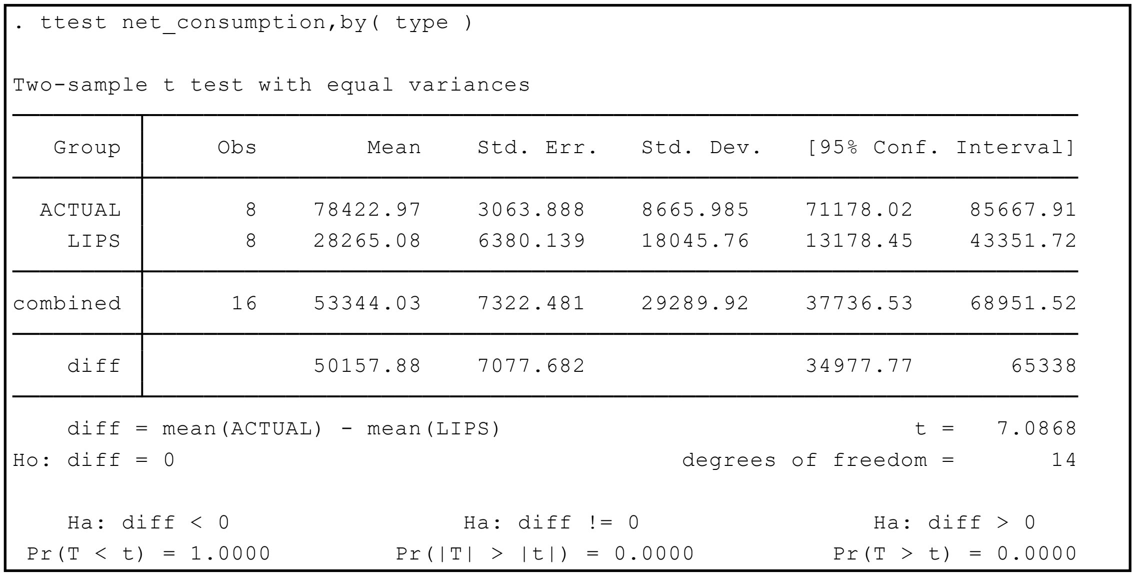
Specific electricity generation capacity

Geothermal

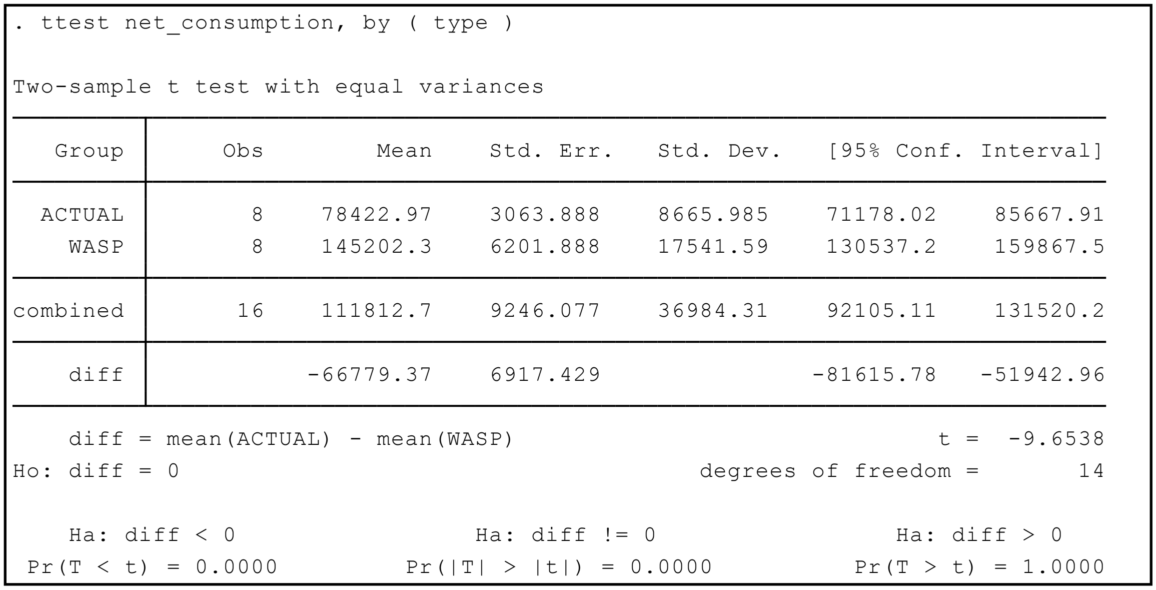


```
. ttest generation_capacity, by ( model )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      15    1150.853    71.14056    275.5262     998.272    1303.435
    WASP |      15      4546.4    448.2294    1735.985    3585.043    5507.757
---------+--------------------------------------------------------------------
combined |      30    2848.627    386.1494    2115.027    2058.863    3638.391
---------+--------------------------------------------------------------------
    diff |           -3395.547    453.8398               -4325.195   -2465.898
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                            t =  -7.4818
Ho: diff = 0                                     degrees of freedom =       28

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```

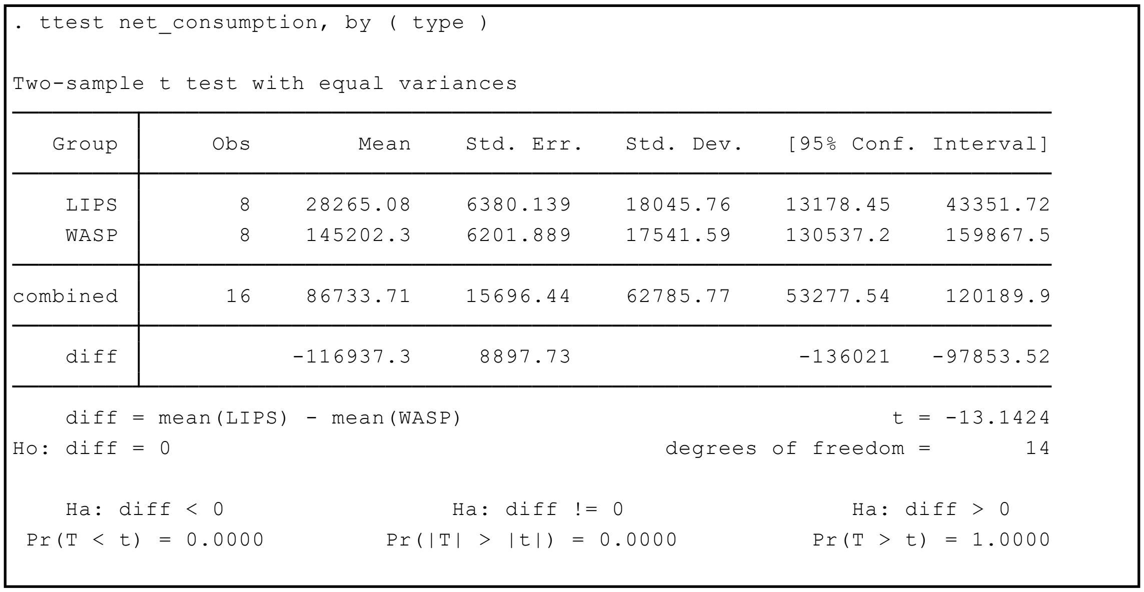
Actual Consumption and LIPS



```
. ttest net_consumption,by( type )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
  ACTUAL |       8    78422.97    3063.888    8665.985    71178.02    85667.91
    LIPS |       8    28265.08    6380.139    18045.76    13178.45    43351.72
---------+--------------------------------------------------------------------
combined |      16    53344.03    7322.481    29289.92    37736.53    68951.52
---------+--------------------------------------------------------------------
    diff |            50157.88    7077.682                34977.77       65338
------------------------------------------------------------------------------
    diff = mean(ACTUAL) - mean(LIPS)                              t =   7.0868
Ho: diff = 0                                     degrees of freedom =       14

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

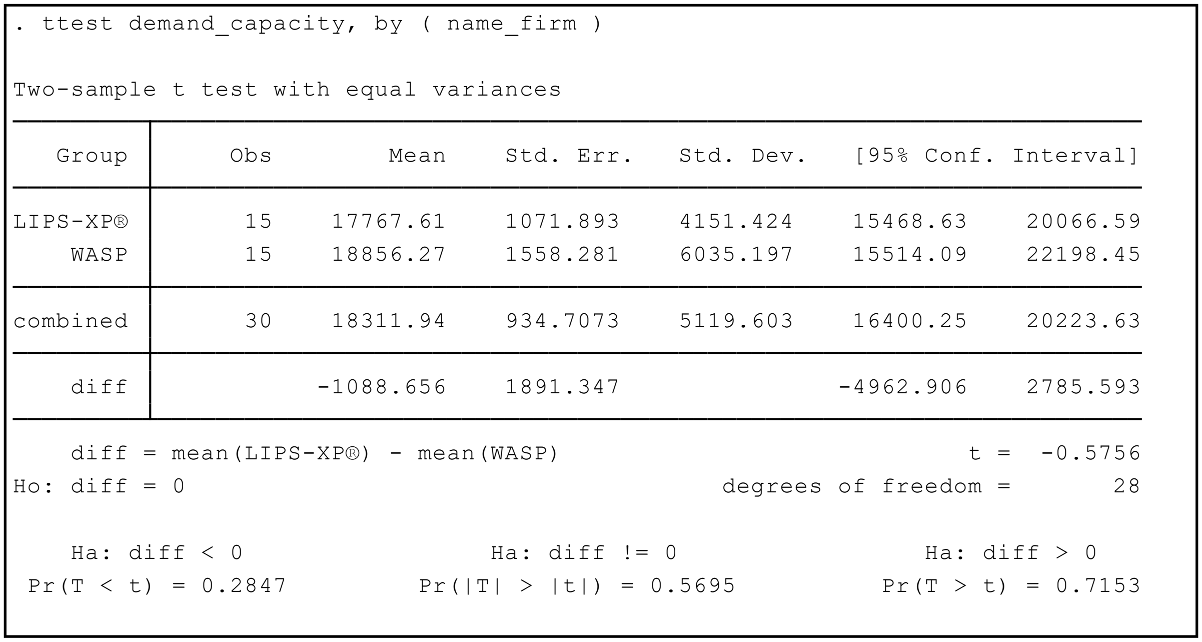


```
. ttest net_consumption, by ( type )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
  ACTUAL |       8    78422.97    3063.888    8665.985    71178.02    85667.91
    WASP |       8    145202.3    6201.888    17541.59    130537.2    159867.5
---------+--------------------------------------------------------------------
combined |      16    111812.7    9246.077    36984.31    92105.11    131520.2
---------+--------------------------------------------------------------------
    diff |           -66779.37    6917.429               -81615.78   -51942.96
------------------------------------------------------------------------------
    diff = mean(ACTUAL) - mean(WASP)                              t =  -9.6538
Ho: diff = 0                                     degrees of freedom =       14

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```



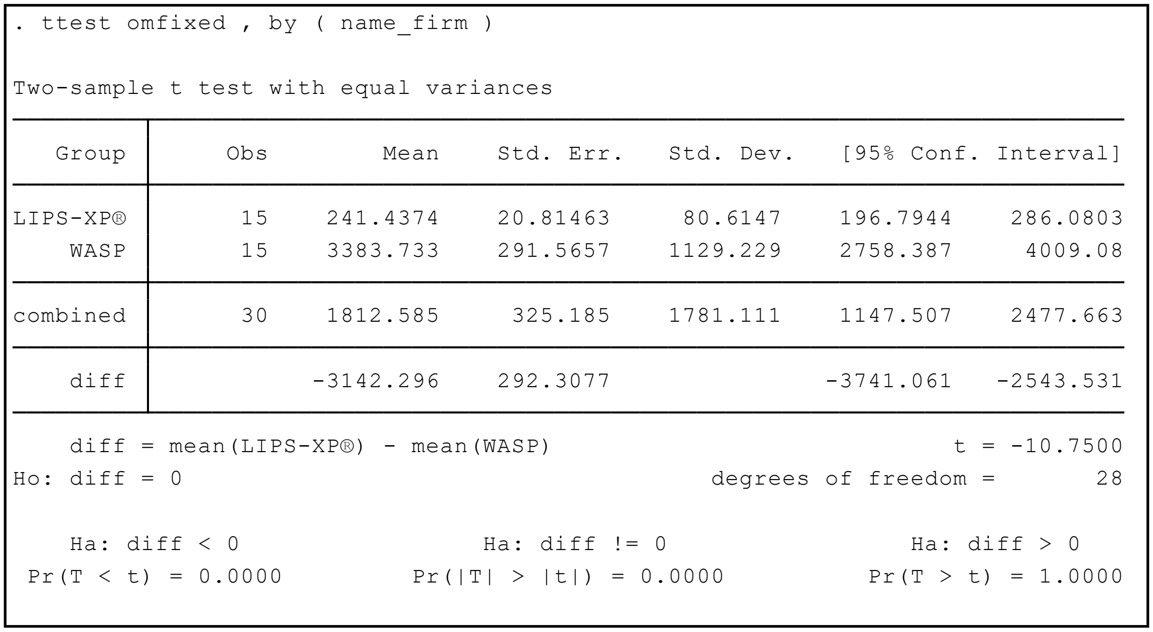
```
. ttest net_consumption, by ( type )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
    LIPS |       8    28265.08    6380.139    18045.76    13178.45    43351.72
    WASP |       8    145202.3    6201.889    17541.59    130537.2    159867.5
---------+--------------------------------------------------------------------
combined |      16    86733.71    15696.44    62785.77    53277.54    120189.9
---------+--------------------------------------------------------------------
    diff |           -116937.3     8897.73                 -136021   -97853.52
------------------------------------------------------------------------------
    diff = mean(LIPS) - mean(WASP)                                t = -13.1424
Ho: diff = 0                                     degrees of freedom =       14

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```

Demand capacity

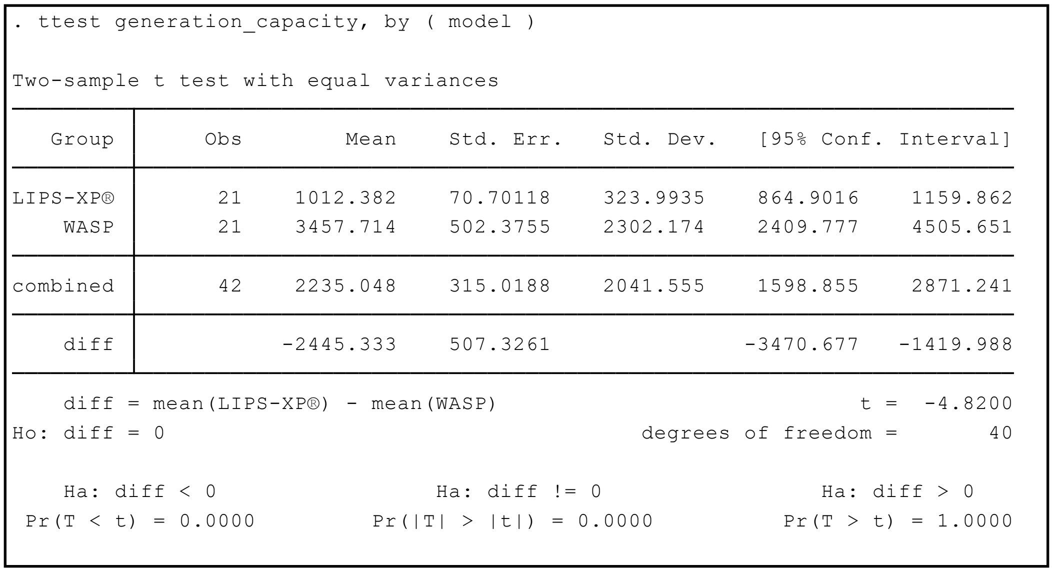


```
. ttest demand_capacity, by ( name_firm )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      15    17767.61    1071.893    4151.424    15468.63    20066.59
    WASP |      15    18856.27    1558.281    6035.197    15514.09    22198.45
---------+--------------------------------------------------------------------
combined |      30    18311.94    934.7073    5119.603    16400.25    20223.63
---------+--------------------------------------------------------------------
    diff |           -1088.656    1891.347               -4962.906    2785.593
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                            t =  -0.5756
Ho: diff = 0                                     degrees of freedom =       28

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.2847         Pr(|T| > |t|) = 0.5695          Pr(T > t) = 0.7153
```

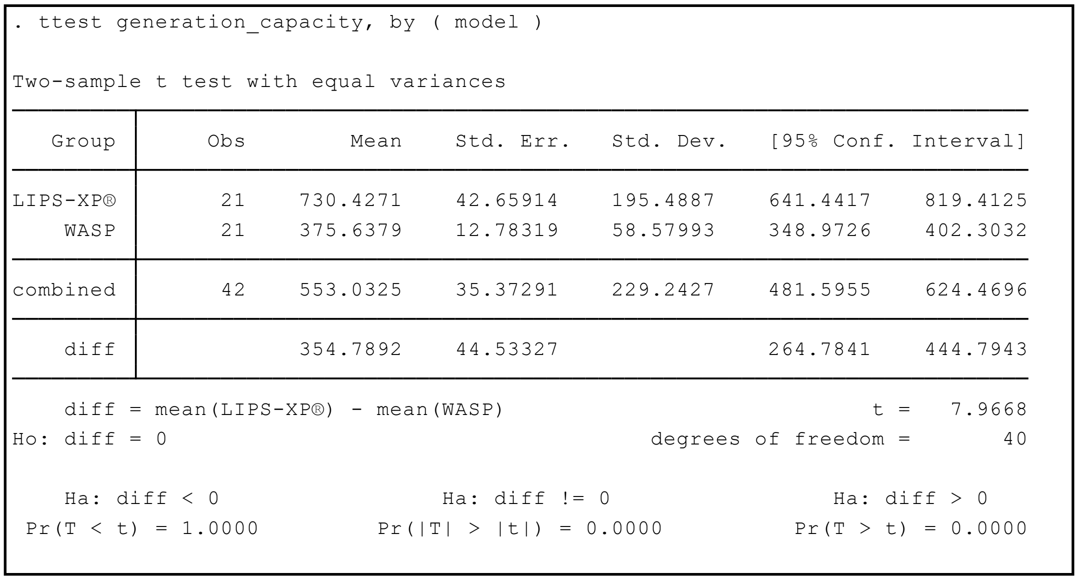
Investment and rehabilitation costs



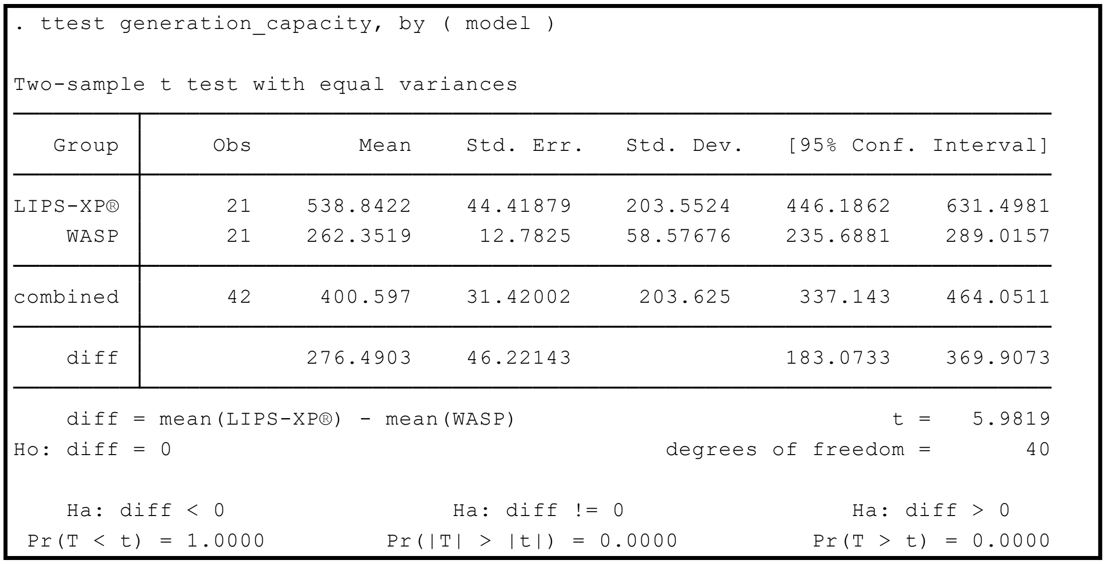
```
. ttest omfixed , by ( name_firm )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      15    241.4374    20.81463     80.6147    196.7944    286.0803
    WASP |      15    3383.733    291.5657    1129.229    2758.387     4009.08
---------+--------------------------------------------------------------------
combined |      30    1812.585     325.185    1781.111    1147.507    2477.663
---------+--------------------------------------------------------------------
    diff |           -3142.296    292.3077               -3741.061   -2543.531
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                            t = -10.7500
Ho: diff = 0                                     degrees of freedom =       28

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```



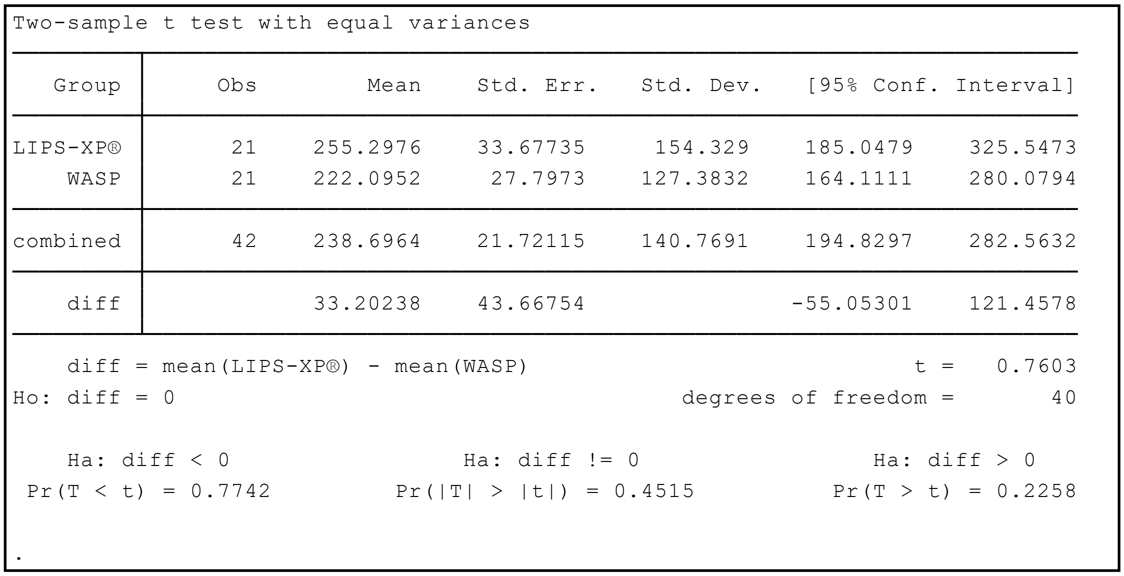
```
. ttest generation_capacity, by ( model )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      21    1012.382    70.70118    323.9935    864.9016    1159.862
    WASP |      21    3457.714    502.3755    2302.174    2409.777    4505.651
---------+--------------------------------------------------------------------
combined |      42    2235.048    315.0188    2041.555    1598.855    2871.241
---------+--------------------------------------------------------------------
    diff |           -2445.333    507.3261               -3470.677   -1419.988
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                            t =  -4.8200
Ho: diff = 0                                     degrees of freedom =       40

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```



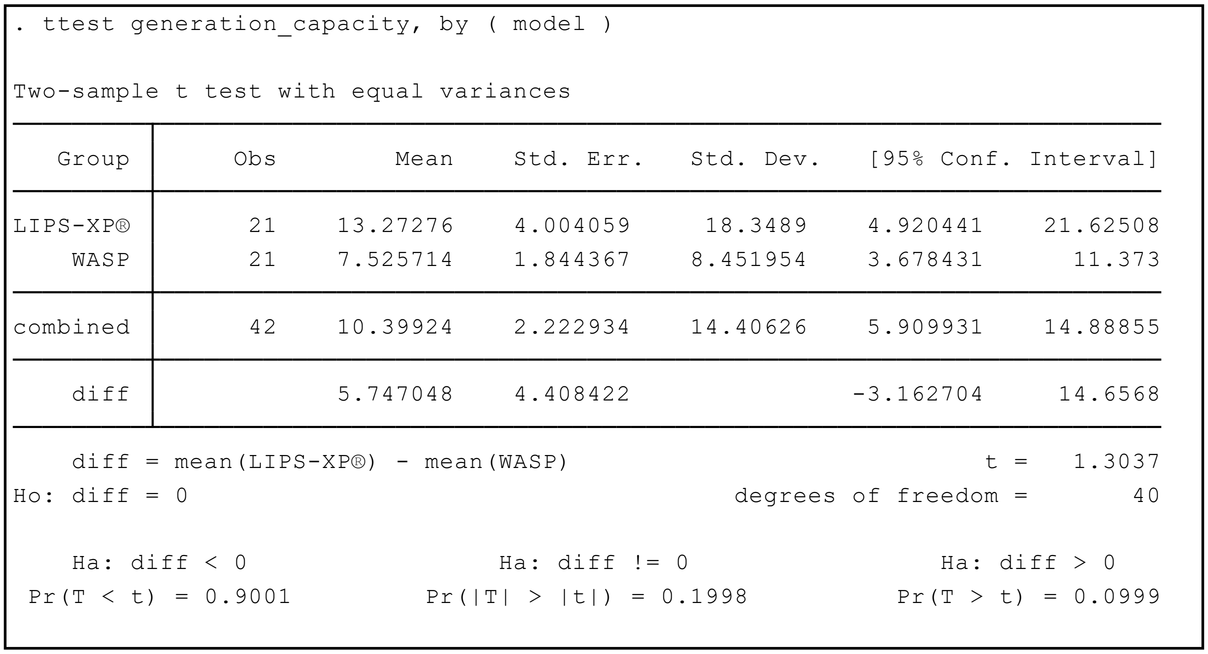
```
. ttest generation_capacity, by ( model )

Two-sample t test with equal variances
─────────┬────────────────────────────────────────────────────────────────────
   Group │     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
─────────┼────────────────────────────────────────────────────────────────────
LIPS-XP® │      21    730.4271    42.65914    195.4887    641.4417    819.4125
    WASP │      21    375.6379    12.78319    58.57993    348.9726    402.3032
─────────┼────────────────────────────────────────────────────────────────────
combined │      42    553.0325    35.37291    229.2427    481.5955    624.4696
─────────┼────────────────────────────────────────────────────────────────────
    diff │            354.7892    44.53327                264.7841    444.7943
─────────┴────────────────────────────────────────────────────────────────────
    diff = mean(LIPS-XP®) - mean(WASP)                            t =   7.9668
Ho: diff = 0                                     degrees of freedom =       40

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```



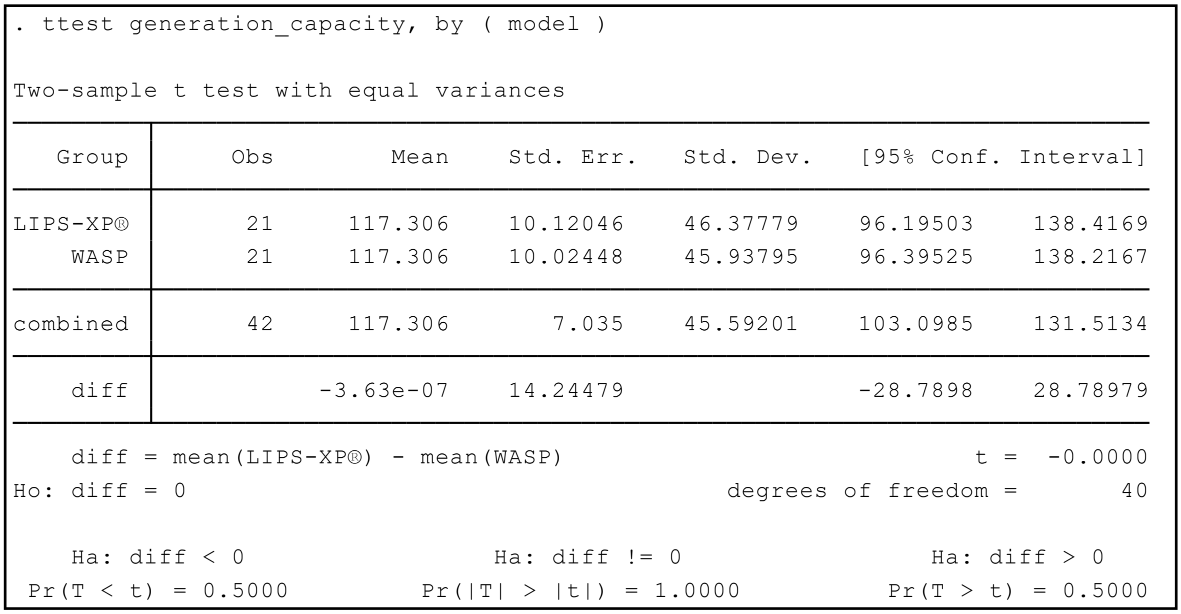
```
. ttest generation_capacity, by ( model )

Two-sample t test with equal variances
─────────┬────────────────────────────────────────────────────────────────────
   Group │     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
─────────┼────────────────────────────────────────────────────────────────────
LIPS-XP® │      21    538.8422    44.41879    203.5524    446.1862    631.4981
    WASP │      21    262.3519     12.7825    58.57676    235.6881    289.0157
─────────┼────────────────────────────────────────────────────────────────────
combined │      42     400.597    31.42002     203.625     337.143    464.0511
─────────┼────────────────────────────────────────────────────────────────────
    diff │            276.4903    46.22143                183.0733    369.9073
─────────┴────────────────────────────────────────────────────────────────────
    diff = mean(LIPS-XP®) - mean(WASP)                            t =   5.9819
Ho: diff = 0                                     degrees of freedom =       40

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```



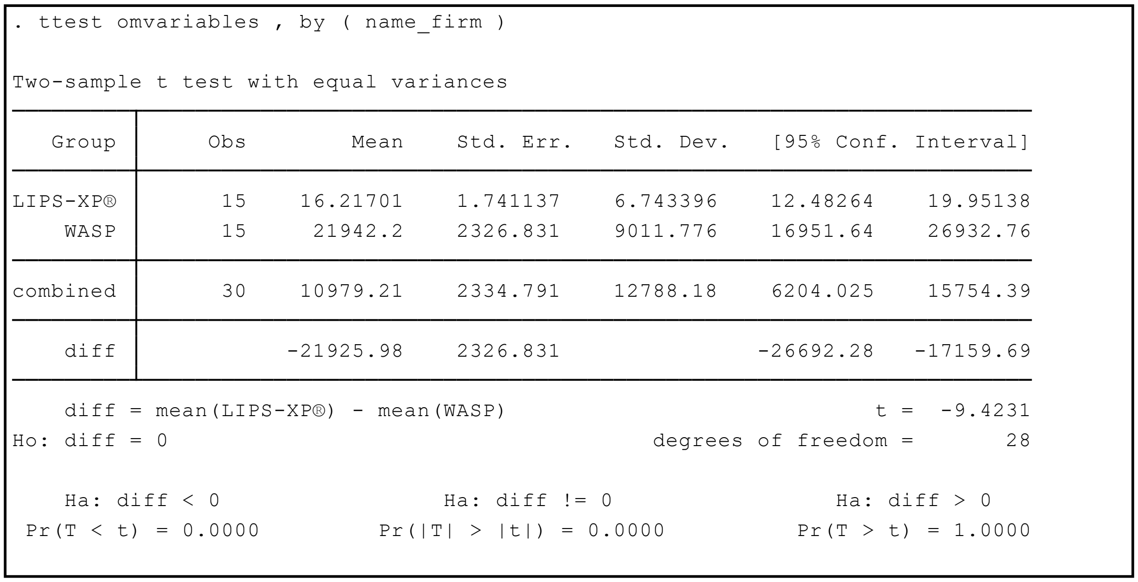
```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      21    255.2976    33.67735     154.329    185.0479    325.5473
    WASP |      21    222.0952     27.7973    127.3832    164.1111    280.0794
---------+--------------------------------------------------------------------
combined |      42    238.6964    21.72115    140.7691    194.8297    282.5632
---------+--------------------------------------------------------------------
    diff |            33.20238    43.66754               -55.05301    121.4578
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                            t =   0.7603
Ho: diff = 0                                     degrees of freedom =       40

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.7742         Pr(|T| > |t|) = 0.4515          Pr(T > t) = 0.2258

.
```



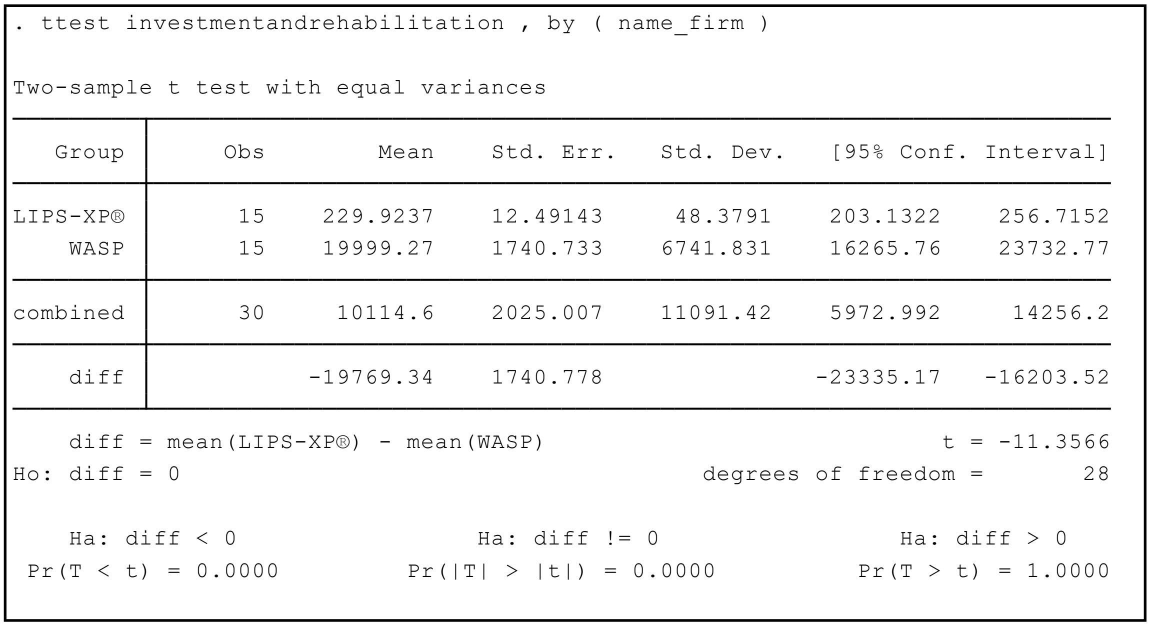
```
. ttest generation_capacity, by ( model )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      21    13.27276    4.004059     18.3489    4.920441    21.62508
    WASP |      21    7.525714    1.844367    8.451954    3.678431      11.373
---------+--------------------------------------------------------------------
combined |      42    10.39924    2.222934    14.40626    5.909931    14.88855
---------+--------------------------------------------------------------------
    diff |            5.747048    4.408422               -3.162704     14.6568
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                            t =   1.3037
Ho: diff = 0                                     degrees of freedom =       40

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.9001         Pr(|T| > |t|) = 0.1998          Pr(T > t) = 0.0999
```



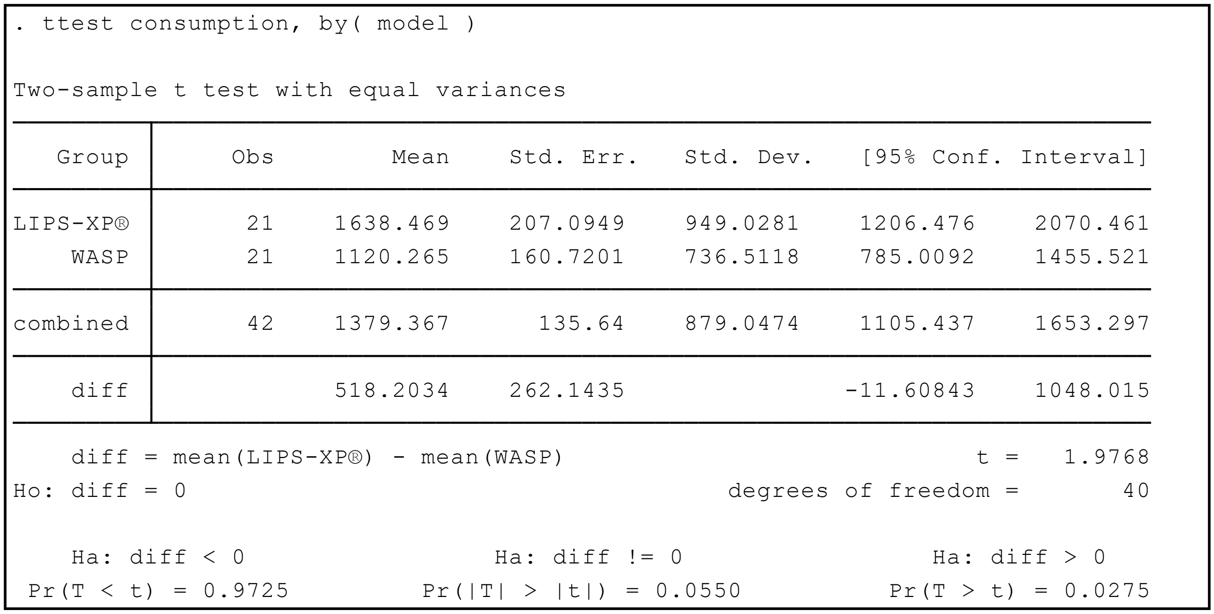
```
. ttest generation_capacity, by ( model )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      21     117.306    10.12046    46.37779    96.19503    138.4169
    WASP |      21     117.306    10.02448    45.93795    96.39525    138.2167
---------+--------------------------------------------------------------------
combined |      42     117.306       7.035    45.59201    103.0985    131.5134
---------+--------------------------------------------------------------------
    diff |           -3.63e-07    14.24479               -28.7898    28.78979
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                            t =  -0.0000
Ho: diff = 0                                     degrees of freedom =       40

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.5000         Pr(|T| > |t|) = 1.0000          Pr(T > t) = 0.5000
```



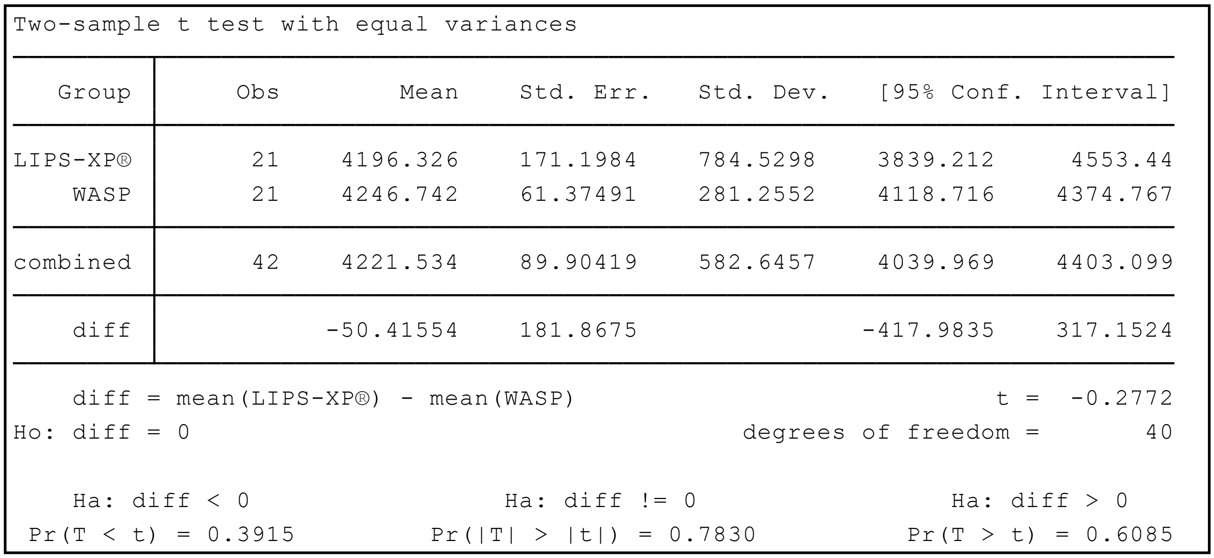
```
. ttest omvariables , by ( name_firm )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      15    16.21701    1.741137    6.743396    12.48264    19.95138
    WASP |      15     21942.2    2326.831    9011.776    16951.64    26932.76
---------+--------------------------------------------------------------------
combined |      30    10979.21    2334.791    12788.18    6204.025    15754.39
---------+--------------------------------------------------------------------
    diff |           -21925.98    2326.831               -26692.28   -17159.69
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                            t =  -9.4231
Ho: diff = 0                                     degrees of freedom =       28

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```



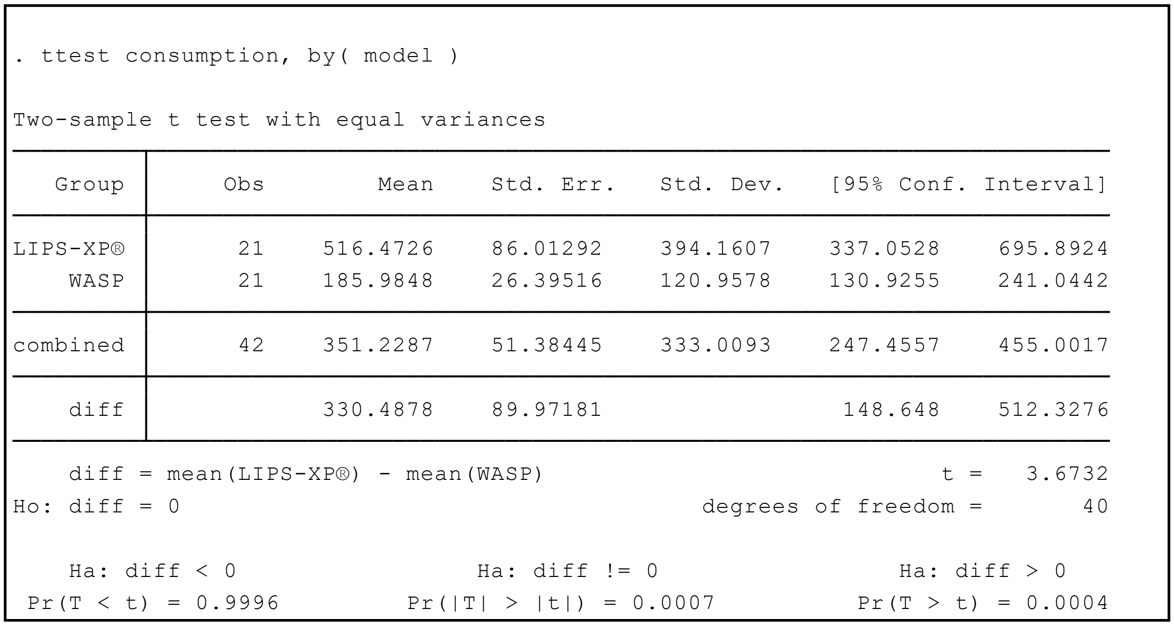
```
. ttest investmentandrehabilitation , by ( name_firm )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      15    229.9237    12.49143     48.3791    203.1322    256.7152
    WASP |      15    19999.27    1740.733    6741.831    16265.76    23732.77
---------+--------------------------------------------------------------------
combined |      30     10114.6    2025.007    11091.42    5972.992     14256.2
---------+--------------------------------------------------------------------
    diff |           -19769.34    1740.778               -23335.17   -16203.52
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                          t = -11.3566
Ho: diff = 0                                     degrees of freedom =       28

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```



```
. ttest consumption, by( model )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      21    1638.469    207.0949    949.0281    1206.476    2070.461
    WASP |      21    1120.265    160.7201    736.5118    785.0092    1455.521
---------+--------------------------------------------------------------------
combined |      42    1379.367      135.64    879.0474    1105.437    1653.297
---------+--------------------------------------------------------------------
    diff |            518.2034    262.1435               -11.60843    1048.015
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                          t =   1.9768
Ho: diff = 0                                     degrees of freedom =       40

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.9725         Pr(|T| > |t|) = 0.0550          Pr(T > t) = 0.0275
```



```
Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      21    4196.326    171.1984    784.5298    3839.212     4553.44
    WASP |      21    4246.742    61.37491    281.2552    4118.716    4374.767
---------+--------------------------------------------------------------------
combined |      42    4221.534    89.90419    582.6457    4039.969    4403.099
---------+--------------------------------------------------------------------
    diff |           -50.41554    181.8675               -417.9835    317.1524
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                            t =  -0.2772
Ho: diff = 0                                     degrees of freedom =       40

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.3915         Pr(|T| > |t|) = 0.7830          Pr(T > t) = 0.6085
```



```
. ttest consumption, by( model )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      21    516.4726    86.01292    394.1607    337.0528    695.8924
    WASP |      21    185.9848    26.39516    120.9578    130.9255    241.0442
---------+--------------------------------------------------------------------
combined |      42    351.2287    51.38445    333.0093    247.4557    455.0017
---------+--------------------------------------------------------------------
    diff |            330.4878    89.97181                 148.648    512.3276
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                            t =   3.6732
Ho: diff = 0                                     degrees of freedom =       40

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.9996         Pr(|T| > |t|) = 0.0007          Pr(T > t) = 0.0004
```

```
. ttest consuption, by( model )

Two-sample t test with equal variances
------------------------------------------------------------------------------
   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
LIPS-XP® |      21    1038.074    64.33861    294.8365    903.8658    1172.282
    WASP |      21    1031.768    65.85569    301.7887    894.3953     1169.14
---------+--------------------------------------------------------------------
combined |      42    1034.921    45.47157    294.6895    943.0892    1126.753
---------+--------------------------------------------------------------------
    diff |            6.305952    92.06752               -179.7694    192.3813
------------------------------------------------------------------------------
    diff = mean(LIPS-XP®) - mean(WASP)                            t =   0.0685
Ho: diff = 0                                     degrees of freedom =       40

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.5271         Pr(|T| > |t|) = 0.9457          Pr(T > t) = 0.4729
```