TECHNO-ECONOMIC ANALYSIS OF OFFSHORE WIND ENERGY POTENTIAL IN LAMU, COASTAL KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree award in any other university.

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DEDICATION

I dedicate this thesis to my lovely mum, siblings, relatives and friends as well as the entire fraternity of teaching staff in the Department of Electrical and Electronic Engineering, Technical University of Mombasa; who have been supportive to me in all manners during my cause of study.

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ABBREVIATIONS

AEO	Annual Energy Output
AEEP	Africa-EU Energy Partnership
BNEF	Bloomberg New Energy Finance
CAPEX	Capital Expenditure
CF	Capacity Factor
EPRA	Energy and Petroleum Regulation Authority
ESMAP	Energy Sector Management Assistance Program
EU	European Union
GOK	Government of Kenya
HOMER	Hybrid Optimization for Multiple Energy Renewables
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
KMFRI	Kenya Marine and Fisheries Research Institute
KENGEN	Kenya Electricity Generating Company
KPLC	Kenya Power and Lighting Company
LAPSSET	Lamu Port – South Sudan – Ethiopia Transport
LCDA	LAPSSET Corridor Development Authority
LCDP	Least Cost Development Plan
LCOE	Levelized Cost of Energy
NPV	Net Present Value
OPEX	Operational Expenditure
OWE	Offshore Wind Energy
OWF	Offshore Wind Farm
PBP	Payback Period
PDM	Power Density Method
RE	Renewable Energy
ROI	Return of Investment
SPP	Simple Payback Period

SSC	Static Series Compensator
STATCOM	Static Synchronous Compensator
SVC	Static VAR Compensator
VAR	Volt-Ampere Reactive
VWF	Virtual Wind Farm
WPD	Wind Power Density
XLPE	Cross-linked Poly-ethylene

DEFINITION OF TERMS

Bloomberg New Energy Finance	This refers to a strategic research provider that global commodity markets and disruptive technologies that drive the transition to low carbon technology.
Cable ampacity	This refers to the maximum current that a cable can bear at the rated temperature.
Capital Expenditure	This refers to initial amount paid for establishing an item or acquiring goods or services.
Internal Rate of Return	This refers to an estimate of future annual rate of return when external factors are excluded.
Levelized Cost of Energy	This refers to unit cost per kilowatt-hour or per megawatt-hour electrical energy that is equivalent of payment stream that has the same value as the total cost of commissioning and operating an electricity generation plant over its life-cycle.
Net Present Value	This refers to the difference between the present value of total cash inflow and the present value of the cash of total cash outflow over a period of time.

Operational Expenditure	This refers to an ongoing cost used for running a system, product or business.
Offshore Wind Energy	This is energy available in wind that can be converted to electrical energy generated via wind farms located in large water bodies such as sea or ocean.
Offshore Wind Farm	This refers to a group of wind turbines usually located in large water bodies such as sea or ocean.
Payback Period	This is the time required to recover the initial cost of an investment or to reach its break-even point.
Renewable Energy	This is the energy that is derived from natural sources which are replenished at higher rate than they are consumed.
Return on Investment	This refers to the approximate measure of probability of an investment.
Static Series Compensator	This flexible solid-state voltage source inverter coupled with transformer to provide controlled voltage compensation when connected in series with a transmission line.
Static Synchronous Compensator	This refers to a module consisting of high power converters that are capable of generating or absorbing a variable

	reactive power to maintain control of specific parameters of a bus.
Static Volt Ampere Reactive Compensator	This refers to group of shunt-connected capacitor and reactor banks with fast control action of thyristor switching to allow regulation of the voltage magnitude.
Volt-Ampere Reactive	This is a unit of measuring reactive power.
Voltage compensator	This is a device that compensates for voltage drops in cable that transmits power to the load over long distances.
Virtual Wind Farm	This is a software based model that is simulated based on the data of a real world wind farm.
Wind Power Density	This refers to the mean annual wind power available per square meter of swept area by wind turbine's blade.

ABSTRACT

Wind power generation has experienced a continuous attention and investment in Kenya. As a country, Kenya borders Indian Ocean that is rich of renewable energy sources such as the offshore wind and tidal waves. In Kenya, the World Bank's funded "Energy Sector Management Assistance Program (ESMAP) has facilitated researches geared to estimate the Offshore Wind Energy (OWE) potentials. These researches have all been potential based. However, for an investment-oriented system, wind energy potential alone is never enough to serve as the only investment parameter. Today, no ocean energy resource system such offshore wind farm has been established to boost the energy requirement and development in Kenyan coastlines. The area of concern in Coastal Kenya is the Lamu. The choice for Lamu as the location of interest for this research work was motivated by expected increase in energy demand for industrialization and shortage of electricity generating plants in Lamu. The expected increase in energy demand is mainly attributed to the proposed development project at Lamu Port and its environs. Lamu Port has three operational berths, which are among the proposed thirty-two. Other consumers include the go downs, hotel industries and other businesses as well as domestic consumers. This research therefore, performed a comprehensive techno-economic feasibility and analysis from offshore wind energy generation system models that geared towards investment forecast in Lamu. To achieve the objectives of this research work, Lamu wind speed and wind direction data were accessed and analyzed during the attachment with Kenya Met. Department. The Lamu load profile data was accessed and analyzed during the attachment with Kenya Power and Lighting Company (KPLC) Limited. Necessary adjustments were made through Mathematical designs. Wind farm models were developed by using application software called Hybrid Optimization for Multiple Energy Renewables (HOMER). Based on the models realized, techno-economic feasibility analysis was achieved. The analysis was made in terms engineering and financial results from the models. Under Vision 2030 projection, the following sets of results were realized: daily peak generation of 50,160 kW, Annual Energy Output (AEO) of 266,204,237 kWh, Net Present Cost (NPC) of $ 1,088,225.00, Levelised Cost of Energy (LCOE) of $ 20.47/MWh, Pay Back Period (PBP) of 3.36 years, and Internal Rate Return (IRR) of 6.13% and Return of Investment (ROI) of 77.87%. Under Vision 2050 projection, the following set of results were realized: daily peak generation of 200,640 kW, AEO of 1,064,816,947 kWh, NPV of $ 285,447.70, LCOE of $ 5.37/MWh, PBP of 3.19 years, IRR of 4.05% and ROI of 76.95%. From the generation capacity and hence AEO achieved for OWFs under Visions 2030 and 2050 projections, would be capable of meeting the projected Lamu's load demands in both scenarios. The values of LCOE, NPV, IRR and ROI would give positive margins, which are clear indications for profitability from Lamu OWFs projected in both scenarios. The PBP for Lamu OWFs projected in both scenarios would both be achieved before the end of the plant's life-cycle period. From these indicators it would therefore be suitable to pursue Lamu OWF investment projects based on projected models under Visions 2030 and 2050.

Key abbreviations: OWE, OWF, VWF, HOMER, AEO, PBP, IRR, NPV, LCOE, ROI