Energy Calculator and Energy System Design Challenge

Objective and Challenge Description

Overview

Develop an energy calculator in Python using Jupiter Notebooks. This tool will assess the total energy output of an off-grid energy system that integrates two renewable sources: a solar photovoltaic (PV) farm and a biomass system (via an anaerobic digester). Teams will design the energy system by determining the proportions of solar and biomass components and then use the calculator to evaluate the energy output across different locations.

Scenario Context:

Community: 200,000 people, each consuming 1,000 kWh per year.

Coffee Processing Factory: A medium-sized facility processing 2,000 tonnes of coffee per year (converting raw coffee beans into instant coffee) and consuming approximately 6,600 MWh per year.

Task Breakdown:

a). **Energy Calculator and System Design**

System Design:

Design an off-grid energy system that combines solar and biomass energy.

Define the proportions (percentage mix) of solar and biomass components.

Output Assessment:

Use the calculator to evaluate your design's performance by incorporating system-specific efficiency values, design specifications, and environmental variables (e.g., geographic coverage and local weather conditions).

Solar Component:

Compute the total energy produced by the installed solar array at each location by accounting for solar irradiation, the installed panel area, and panel efficiency.

Generate a separate performance report for each of the following locations: Kasese, Lira, and Mbale.

Biomass Component:

Calculate the total daily feedstock volume from two sources:

Human Waste: Assume each person generates 0.56 litres of faecal sludge per day. (Convert litres to cubic metres using 1,000 L = 1 m^3.)

Coffee Processing Waste: With an annual processing capacity of 2,000 tonnes and assuming 51% waste generation, determine the daily biomass waste (assuming a density of roughly 1 tonne/m³).

Using an assumed hydraulic retention time (HRT) of 30 days, compute the required digester volume.

Assume a biogas yield of 20 m³ per tonne of feedstock and a calorific value of 6 kWh per m³ to estimate the daily energy output from the digester.

Business Plan and Implementation.

Cost Analysis:

Determine the cost of implementing the system at each location.

Provide detailed calculations for capital expenditures and include commentary on expected operation and maintenance costs.

Battery Storage Unit:

Assume a battery storage unit (e.g., a 15-kWh battery) with dimensions of 640×450×640 mm and an average cost of $4,500 per unit.

Determine the total number of solar panels required to generate the energy needed to charge one battery unit (using your calculated daily energy production) and, in turn, the number of battery units required to meet the total energy demand.

Business Plan and Implementation Sketch

Based on your energy calculations, determine the system configuration that best meets the energy demands at the specified locations (Kasese, Lira, and Mbale) and analyse the associated costs.

Develop a comprehensive business plan addressing:

System cost and scalability.

Complementary energy storage solutions (e.g., batteries).

Land and resource requirements.

Create a conceptual 3D Sketchup drawing (or equivalent mock-up) that illustrates the proposed energy system implementation on a greenfield site at your preferred location (select one from Kasese, Lira, or Mbale). Justify your location choice based on economic factors.

Presentation

Prepare an 8–10 slide presentation summarizing your energy system design, energy output analysis, business plan, and implementation mock-up.

Present your work to a panel of judges, highlighting the commercialization potential of your solution.

Technical Guidance and Design Specifications

Solar Photovoltaic Layout

Panel Specifications:

Rated Capacity: 300 W per panel.

Panel Area: Approximately 1.7 m^2 per panel.

Efficiency: 20% (baseline efficiency).

Average Cost: Approximately $1,500 per panel.

Design Considerations:

Solar Irradiation: Use the provided global solar atlas to determine the solar irradiation (in $kWh/m^2/day$) and the photovoltaic output at each location. Calculate the mean weighted solar irradiation if necessary.

Energy Production Calculation:

Use the formula: Daily Energy = Panel Area × Solar Irradiation × Panel Efficiency Multiply the daily energy per panel by the number of days in a year to obtain annual production.

Total Solar Energy Produced:

Calculate the total energy produced by the installed solar array at each location by inputting the total installed area (or number of panels) into your calculator. This energy output will contribute to the overall energy supply, which must be compared with the energy demands of the community and the processing facility.

Layout and Land Requirements:

Panels should be arranged in rows with sufficient spacing to minimize shading and allow for maintenance.

For planning purposes, assume that 1 MW of installed capacity requires approximately 6 acres (or 2.43 hectares) of land.

Biomass Anaerobic Digester

Feedstock Sources:

Human Waste:

Assume each person generates 0.56 litres of faecal sludge per day.

Calculate the total daily volume for 200,000 people (remember to convert litres to cubic metres: 1,000 L = 1 m^3).

Coffee Processing Waste:

With an annual processing capacity of 2,000 tonnes and assuming 51% is converted into biomass waste, determine the daily waste generated (assume a density of roughly 1 tonne/m^3).

Design Considerations:

Total Daily Feedstock Volume:

Sum the volumes of faecal sludge and coffee processing waste to determine the total daily volume.

Hydraulic Retention Time (HRT):

Assume an HRT of 30 days to determine the necessary digester volume: Required Digester Volume = Daily Feedstock Volume × HRT

Land Requirements for Digester:

Assuming the digester is constructed as a modular tank with an average height of 6 meters, determine the footprint area by dividing the total volume by 6.

Biogas Yield and Energy Calculation:

Assume a biogas yield of 20 m^3 per tonne of feedstock.

Calculate the total daily biogas production by multiplying the daily feedstock mass by this yield.

With a calorific value of 6 kWh per m^3, compute the total daily energy produced by the digester: Daily Energy from Digester = Total Biogas Produced× 6 kWh/m3

Total Energy Produced

Overall Energy Supply:

Sum the total energy produced by the solar array and the energy produced from the biomass (biogas) to determine the overall daily energy supply.

3. Other Considerations

Energy Demand Calculation:

Calculate the total energy demand of the community and the coffee processing factory. This will be essential for determining the necessary energy supply.

Using the Energy Calculator:

Your coded energy calculator should compute:

Total energy demand of the community,

Energy generated by the solar component,

Energy produced by the biomass component,

Combined total energy supply,

Total battery storage requirements, and

Total land occupied by the energy system and batteries.

Clearly indicate intermediate variables and output your results using code chunking wherever possible. Use your judgment to select and justify these variables.

Solar Panel and Battery Sizing:

Decide whether the number of solar panels should be defined by the residual energy supply after accounting for the biomass contribution or by the number needed to charge a 15kWh battery storage unit.

Rules and Tools

Team Formation:

Eligible students (S3 and S5) with strong skills in Physics, Economics, and Mathematics may form teams of up to 6 members.

Teams may subdivide into two groups of 3 to work concurrently on the energy system design/calculator and the business plan/implementation sketch.

Submission Guidelines:

Energy Calculator and System Design:

Submit the source code along with detailed instructions for accessing your solution.

Deadline: 26th May 2025

Email: vivacollegeschool234@gmail.com (CC: **stella.nkera2020@gmail.com**)

Business Plan and Implementation Sketch:

Submit a comprehensive business plan, including the 3D Sketchup drawing/mock-up

Deadline: 26th May 2025

Email: vivacollegeschool234@gmail.com (CC: **stella.nkera2020@gmail.com**)

Presentation:

Present an 8–10 slide summary of your energy system design, energy output analysis, business plan, and mock-up to the judges.

Date: 14th June 2025 (10-minute pitch + 5-minute Q&A).

Judging Criteria:

Code quality, logical clarity, and efficient syntax.

Accuracy and applicability of the energy production and demand calculations.

Innovation in system design and strategic allocation of solar and biomass components.

Commercial viability and comprehensiveness of the business plan.

Quality and clarity of the 3D Sketchup drawing/mock-up and overall presentation.

Integrity:

All submissions must be entirely original.

Non-adherence to guidelines or plagiarism will result in disqualification.

AMA Sessions for Additional Support:

Software Engineering/Computer Science Guidance:

AMA Session: **5th May 2025**

Business Plan Guidance:

AMA Session: **28th June 2025**

Useful Links:

Global Solar Atlas: [Global Solar Atlas Uganda]

Solar Energy Technology Primer: [Solar Energy Technology Primer PDF]

How Does Anaerobic Digestion Work: [EPA Guide]

Glossary of Terms

Efficiency: The ratio of useful energy output to the total energy input, expressed as a percentage.

Solar Irradiation: The power per unit area received from the sun, typically measured in $kWh/m^2/day$.

Photovoltaic (PV) Panel: A device that converts sunlight into electrical energy using the photovoltaic effect.

Anaerobic Digestion: A biological process that breaks down organic matter in the absence of oxygen to produce biogas.

Hydraulic Retention Time (HRT): The average time that feedstock remains in the digester.

Biomass: Organic material derived from living or recently living organisms, used as fuel.

Biogas: A mixture of gases (mainly methane and carbon dioxide) produced by anaerobic digestion.

kWh (Kilowatt-hour): A unit of energy representing the consumption of 1,000 watts for one hour.

MWh (Megawatt-hour): A unit of energy representing the consumption of 1,000,000 watts for one hour.

Greenfield Site: An undeveloped area used for new projects, free of prior infrastructure.

6. Conclusion

This challenge integrates renewable energy engineering, programming, and business planning. By focusing on a solar PV farm and a biomass anaerobic digester, you will design a custom energy system that determines the optimal mix of these two resources and evaluates its performance by calculating the total energy produced at each location. Your business plan will incorporate cost assessments—including battery storage (using a 15-kWh unit with dimensions of 640×450×640 mm at an average cost of $4,500) and resource requirements—while your implementation mock-up will illustrate the system's viability on a greenfield site selected based on economic factors. Good luck as you innovate toward a greener, more energy-efficient future!