OPTIMIZATION STRATEGIES FOR SUSTAINABLE ENERGY DEVELOPMENT IN ANGOLA – A MULTI-STAGE APPROACH –

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CONTENTS

OBJECTIVES

- Present a mathematical model to support the decision making process related to the planning of capacity and operation of hybrid electrical energy systems.

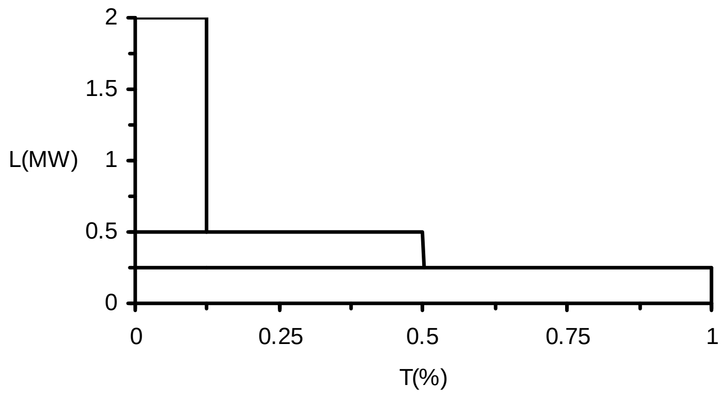
- Contribute to the development of procedures to assist in making decisions associated with the composition and operation of autonomous hybrid systems.

- Contribute to find sustainable solutions that contribute to minimizing the cost of energy needs of rural populations in Angola.

THE CASE STUDY (1)

Three real-world case studies involving the villages of Ambriz, Muxiluando and Tombwa, in Angola

- Village of Ambriz – Current Energy Needs



LDC – Energy needs for a daily cycle

$$Q = 2.1\,\mathrm{MW}$$

$$E = 13.2\ \mathrm{MWh/day}$$

THE CASE STUDY (2)

- Alternatives for Energy Generation
  - Thermal (diesel generators: 600 kW, 10 years)
  - Hydro (small dam: 7000 kW)
  - Photovoltaic (solar panels: 300 kW, 20 years)

- Costs of Construction and Operation
  - Thermal: I=285 kUSD, CF=20kUSD/year, cv=0.28 USD/kWh
  - Hydro: I=23415 kUSD, CF=1079 kUSD/year
  - Photovoltaic: I=1338 kUSD, CF=53 kUSD/year

EQUIVALENT COSTS (1)

- Equivalent acquisition cost
  - Introduction of capacity with end-of-life renewal

$$\underbrace{I + \frac{I}{(1+r)^n - 1}}_{PV(I_0)+PV(I_n)+PV(I_{2n})+\dots} + \frac{CF}{r} = \frac{CA_R}{r}$$

  - Introduction of capacity only once

$$\underbrace{I + \frac{CF}{r}\left(1 - \frac{1}{(1+r)^n}\right)}_{PV(CF)} = \frac{CA_S}{r} \quad \longrightarrow \quad CA_S = CA_R \frac{(1+r)^n - 1}{(1+r)^n r}$$

EQUIVALENT COSTS (2)

- Equivalent acquisition cost per unit of capacity
  - Introduction of capacity with end-of-life renewal

$$cr = \{0.2443, 0.6971, 1.3056\} \qquad \frac{\$}{kW\ day}$$

  - Introduction of capacity only once

$$cs = \{0.0625, 0.1784, 0.3341\}$$

UNCERTAINTY CHARACTERIZATION

- Power needs described by a generalized Wiener process

$$dU\left(t,W\right)=\mu\, dt+\sigma\, dW \qquad E_T\left[U\right]=2U_0 \qquad Var_T\left[U\right]=\frac{2}{3}U_0^2$$

- Trinomial tree of the power needs for Ambriz

τ								
	0				2000 1			
	1			1600 0.3704	2800 0.3703	4000 0.2593		
	2		1200 0.1372	2400 0.2743	3600 0.3292	4800 0.1921	6000 0.0672	
	3	800 0.0508	2000 0.1524	3200 0.2591	4400 0.2642	5600 0.1814	6800 0.0747	8000 0.0174
	s	-3	-2	-1	0	1	2	3

THE UNDERLYING LP MODEL

- The objective is to set the generation capacity such that the equivalent investment costs plus the operating costs are minimized.
- The constraints are related with the capacity of the power plants, with the available power and with energy transference between nearby localities.

$$Min\ \ C_T = \sum_j cr_j x_j + \sum_i \sum_j f_j \beta_i y_{ij} + P_D \sum_i \beta_i d_i - \sum_j \left(P_E - f_j\right) E_j$$

s.t.

$$\sum_i \beta_i y_{ij} + E_j - \beta_1 x_j = 0, \quad \forall j \in J$$

$$\sum_i y_{ij} + q_j - x_j = 0, \quad \forall j \in J$$

$$\sum_j y_{ij} + d_i = w_i, \quad \forall i \in I$$

$$x_j - Q_j z_j = 0, \quad \forall j \in J$$

$$\sum_j x_j \le Q_u$$

$$x_j, y_{ij}, q_j, d_i, E_j \ge 0\ ,\ \ z_j \in \mathbb{Z}, \quad \forall i \in I, \forall j \in J$$

THE STOCHASTIC MULTI-STAGE MODEL

- The objective is to minimize the expected value of the total annual cost over the planning horizon:

$$Min \sum_{\tau \geq 1} \gamma_{\tau-1} E\left\{ \sum_j c_j^{\tau-1} x_j^{\tau-1} + \alpha_\tau \left[\sum_i \sum_j f_j \beta_i y_{ij}^\tau + P_D \sum_i \beta_i d_i^\tau - \sum_j \left(P_E - f_j \right) E_j^\tau \right] \right\}$$

- Starting from the last stage:

$$Q_{\tau_T-1}\left(x_{\tau_T-1}, u_{\tau_T-1} \right) =$$

$$Min \ \gamma_{\tau_T-1} \left\{ \sum_j c_j^{\tau_T-1} x_j^{\tau_T-1} + \alpha_{\tau_T} E\left[\sum_i \sum_j f_j \beta_i y_{ij}^{\tau_T} + P_D \sum_i \beta_i d_i^{\tau_T} - \sum_j \left(P_E - f_j \right) E_j^{\tau_T} \right] \right\}$$

- Expected value of the contributions for the total cost:

$$\bar{Q}_{\tau_T-1}\left(x_{\tau_T-1} \right) = E\left[Q_{\tau_T-1}\left(x_{\tau_T-1}, u_{\tau_T-1} \right) \right] = \sum_{s=-\tau_T+1}^{s=\tau_T-1} P\left(\tau_T - 1, s \right) Q_{\tau_T-1}\left(x_{\tau_T-1}, u_{\tau_T-1} \right)$$

RESULTS (1)

- Capacity decisions if there is no energy transfers between locations – Expected total fixed cost is 4085 USD/day

τ	0			3000 0 1200		
	1		2400 0 1200	3600 0 1200	0 7000 0	
	2	2400 0 900	3000 0 1500	0 7000 0	0 7000 0	1200 7000 0
	s	-2	-1	0	1	2

- With the underlying LP model we get 4662 USD/day

RESULTS (2)

- Capacity decisions if 5% of the surplus energy is transferred – Expected total fixed cost is 3587 USD/day

τ					
0			1800 0 1200		
1		1200 0 1200	0 7000 0	0 7000 0	
2	1200 0 900	0 7000 0	0 7000 0	0 7000 0	0 7000 0
s	-2	-1	0	1	2

CONCLUSION

- This study shows that the use of natural resources, namely hydropower, has economic advantages even when energy needs are lower than the potential of the generation available
- We also found that, even in a small scale, the interaction with other locations lead to significant economical advantages. And, this is particularly important because, presently, solutions are defined without considering it.
- In practice, the decision-making process on these issues always involves uncertainty and the possibility of changing decisions made previously. And the results presented show that this has to be taken into account in decision support models.

Thank You for Your Attention