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## Article

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# Analysis of evolution scenarios of Santiago Island energy sector in Cabo Verde

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## Abstract

The main purpose of this work is to establish and analyze distinct scenarios for the evolution of the energy system of the island of Santiago in Cabo Verde in the long term, that is, within the time horizon of 2040. The *LEAP (Long-Rang Energy Alternatives Planning)* simulation tool was used to simulate future projections of the evolution of energy system through insertion of demand data, transformation and resources. Three scenarios were established to project the energy matrix and to analyze the behavior of parameters such as the final energy demand of sectors as the domestic, commerce/industry/services, hoteliers, public institutions, desalination, thermoelectric power plant and total electric losses. It is observed that the current trend of the island's is an increase in the total demand for energy and should reach an efficient scenario of approximately 670 GWh in 2040, which is more than three times that of 2017.

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**Keywords:** Energy consumption; Energy system; Santiago Island; Renewable energy resources

## 1. Introduction

The energy situation of small island states, such as the Cabo Verde archipelago, depends to a great extent on the import of fossil fuels, mainly oil and its derivatives, to meet their energy demands. According to Chen et al. [1], the increase in global energy demand and the environmental problems related to the use of fossil energy require new energy sources to replace traditional fossil fuels. It is also assumed that the global development of renewable energy technologies can ensure the sustainable supply of energy to the islands. According to Ranaboldo et al. [2], although Cabo Verde has both wind and solar power (integration of wind and solar energy into its energy system), the conventional strategy to increase access to electricity, particularly in rural areas (isolated) is through centralized microgrids with diesel generators. However, Sheikh et al. [3] state that social and political perspectives, in which

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## Nomenclature

LEAP	long rang energy alternatives planning system
GWh	gigawatt hour
INE	national statistics institute - Cabo Verde
DGE	general directorate of energy - Cabo Verde
Electra	concessionaire of production and distribution of energy and water - Cabo Verde
MW	megawatt
MWh	megawatt hour
TOE	tonne of oil equivalent
GDP	gross domestic product
GHG	greenhouse gases
CO <sub>2eq</sub>	carbon dioxide equivalent

they may have positive, negative or combination impacts, are important elements/parameters for renewable energy technologies. Positive impacts can improve the adoption of certain technologies and adverse ones can reduce the intended benefits or even threaten the viability of a technologically promising technology. Energy policy must take into account the development of low pollutant emission energy technologies, which involves the challenges of the gradual depletion of coal, oil and natural gas reserves, as well as the mitigation of climate change, mainly contributing to the achievement of the objectives of sustainable development in three dimensions: economic, social and environmental [4]. Renewable energy technologies in particular offer diverse and economically attractive options to provide accessible and sustainable energy for millions of people, particularly for rural electrification [5].

## 2. Methodology

The LEAP (Long-Rang Energy Alternatives Planning) software was used as an integrated modeling tool to simulate, among others, future projections of evolution of energy systems, greenhouse gas mitigation analysis, through insertion of demand data, transformation and resources from year base [6]. The data used in this study were researched and collected from some Cape Verdean organizations, namely (i) National Statistics Institute (INE) [7], (ii) General Directorate of Energy (DGE) and (iii) *Electra*, concessionaire of production and distribution of energy and water of Cabo Verde [8]. In this work were developed various scenarios of the energy system until a time horizon in 2040, considering demographic, political, economic, technological and environmental trends, in order to provide energy sustainability. The base year of 2017 was chosen because it has a significant amount of economic and technological data available.

## 3. Geographic, demographic and climatic characterization

Cabo Verde is small country consisting of ten islands and is located between latitudes 14°28' N and 17°12' N and longitudes 22°40' W and 25°22' W. It is located approximately 500 km from the Senegal coast in West Africa [9]. It has a total area of 4033 km<sup>2</sup> and a total population of 543 492 inhabitants. The Cape Verde archipelago is an integral part of the Sahel, characterized by a dry tropical climate with two distinct climatic seasons: a dry season (November to June) and a rainy season (July to October). Santiago is the largest (991 km<sup>2</sup>) and most populous island (305 573 inhabitants) of Cabo Verde. According to the demographic projection of INE [10], it is estimated that the Santiago island will have 348 824 inhabitants in 2030.

## 4. Energy balance

### 4.1. Installed electrical generation capacity

The Table 1 shows that there has been a continuous increase of installed electrical energy generation capacity on Santiago Island, predominantly consisting of the conventional thermal source. In 2017, nominal installed capacity totaled 111.14 MWe (against 55.32 MWe in 2012), distributed by diesel (96.79 MWe), wind (9.35 MWe) and photovoltaic (5.0 MWe).

**Table 1.** Evolution of the nominal electrical power (MWe) installed on Santiago island (elaboration from the data in [8]).

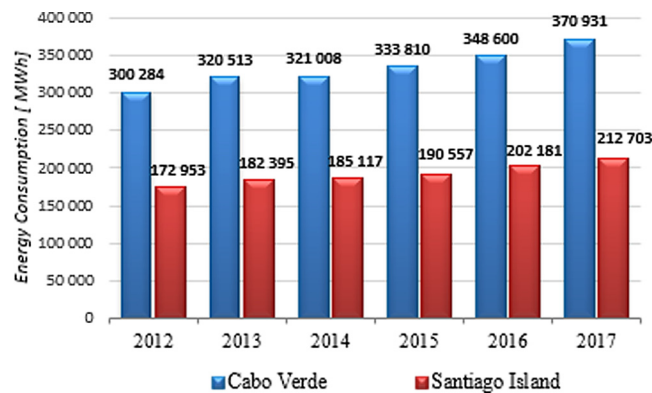
Installed electrical generation capacity [MWe]	2012	2013	2014	2015	2016	2017
Thermal	40.97	62.85	62.85	83.78	88.47	96.79
Wind	9.35	9.35	9.35	9.35	9.35	9.35
PV Solar	5.0	5.0	5.0	5.0	5.0	5.0

#### 4.2. Electrical energy production and consumption

Table 2 and Fig. 1 illustrates the production and consumption of electricity in Cape Verde over the last 5 years, with particular emphasis on Santiago Island. The electrical energy available for consumption in the archipelago reached, in 2017, the value of 424 798 MWh (36 526 TOE). The island of Santiago was the one that obtained the most electrical energy available for consumption by the population, reaching a value of 241 795 MWh (20 791 TOE). As shown in Fig. 1, between 2012 and 2017, the energy consumption on Santiago Island showed an average annual growth rate of approximately 4.6%.

**Table 2.** Evolution of final electricity production in Cabo Verde and Santiago Island (elaboration from the data in [8]).

Energy production [MWh]	2012	2013	2014	2015	2016	2017
Cabo Verde	330 197	354 834	360 624	377 113	395 191	424 798
Santiago Island	187 343	197 645	205 855	212 280	224 996	241 795

**Fig. 1.** Evolution of final electric energy consumption in Cabo Verde and Santiago Island (elaboration from the data in [8])

#### 4.3. Renewable energy resources

In 2017, about 35 482 MWh of electric energy was produced from renewable sources in the island of Santiago (Table 3).

**Table 3.** Contribution of electric energy production from renewable sources in Santiago island (elaboration from the data in [8]).

	2012	2013	2014	2015	2016	2017
Wind [MWh]	28 366	34 510	33 742	31 699	32 121	31 350
PV Solar [MWh]	5 823	4 864	5 367	4 034	3 495	4 132

### 5. Analysis and discussion of results of energy's projections

#### 5.1. Final energy demand

The final energy demand is one of the main parameters of the simulation, revealing the behavior of the energy consumptions in several sectors. However, LEAP model was built to analyze the future trends of energy structure and

carbon emission from the base year 2017 to 2040 on Santiago Island under three scenarios: Reference, Intermediate and Efficient (Table 4).

**Table 4.** Socio-economic indicators for projection of electrical energy on Santiago Island.

Scenario	Average annual growth rate in %	
	Economic (GDP)	Demographic (population)
Reference	3, 9	1, 23
Intermediate	5, 2	1, 25
Efficient	7, 0	1, 28

It is estimated that the final energy demand has a growing tendency in various scenarios analyzed until the year 2040 (Table 5). The highest growth of energy demand would be for the Efficient scenario (under the assumption in energy production growth of 11% by wind and 18% by photovoltaic solar until 2040). This increase can be explained as a result of the forecast of the demographic and GDP increase, which would lead to a in the use of electricity, especially in the domestic sector. For the Reference scenario (under the assumption in energy production growth of 5% by diesel, 5% by wind and 10% by photovoltaic solar until 2040), there is an increase in demand for final energy at a rate of 4.6% per year, from 209 553 MWh in 2017 to 431 521 MWh in 2040. In the Intermediate scenario, (under the assumption in energy production growth of 2,5% by diesel, 7% by wind and 14% by photovoltaic solar until 2040), there is a trend higher for the final energy demand, contrary to the Reference scenario (around 7.6% per year), reaching 578 017 MWh in 2040.

**Table 5.** Final energy demand [GWh] in all sectors up to 2040 on Santiago Island.

Scenarios	2017	2019	2020	2022	2024	2026	2028
Reference	209.5	226.8	235.5	253.2	271.3	289.7	308.5
Intermediate	209.5	237.0	251.0	279.5	308.7	338.7	369.6
Efficient	209.5	242.6	259.4	293.9	329.4	366.2	404.3
Scenarios	2030	2032	2034	2036	2038	2040	
Reference	327.8	347.5	367.7	388.4	409.6	431.5	
Intermediate	401.5	434.4	468.4	503.6	540.1	578.0	
Efficient	444.0	485.2	528.2	573.1	620.1	669.2	

## 5.2. Total installed capacity and energy losses

According to the projection of the results presented in Table 6, in the Reference and Efficient scenarios, the annual growth rate of the total installed electric power generation capacity will be of 10.2% and 12.3%, respectively, while in the Intermediate scenario this growth rate would be lower, corresponding to 8.1%.

**Table 6.** Total installed electric power generation capacity and corresponding growth rates (authors' elaboration).

Scenarios' name	Reference	Intermediate	Efficient
Total installed electric power capacity [MW]	370.78	316.93	424.93
Growth rate [%]/year	10.2	8.1	12.3

It can be seen from Table 7 that in the different scenarios, the amount of electric energy losses in the distribution network decreases from 2018 to 2040, as a direct consequence of the values assigned (2017-36.3% and 2040-9.0%) in the percentage reduction of losses, that is, 11.7% in the *Reference* scenario, 10.2% in the *Intermediate* scenario and 9.1% in the *Efficient* scenario. It is predicted that, in an *Efficient* scenario, the technical losses in the electricity grid will be close to 9.0% in the year 2040.

## 5.3. Electrical energy production

As can be seen in Table 8, there is a greater weight of total electrical energy production in the Reference scenario compared to the other scenarios due to a decrease of only 5.0% in diesel production compared to the Intermediate

**Table 7.** The electricity losses and corresponding growth rates (authors' elaboration).

	Base year (2017)	Year 2040		
		Reference	Intermediate	Efficient
Electricity losses [MWh]	39 464	12 720	11 089	9 893
Growth rate [%]/year	–	2.9	0.6	0.5

**Table 8.** The electricity production and corresponding growth rates (authors' elaboration).

Scenarios' name	Reference	Intermediate	Efficient
Energy production [GWh]	766 989	596 814	737 959
Growth rate [%]/year	9.4	6.4	8.9

scenario (2.5%). In the Efficient scenario, the diesel production remained the same as in the base year (2017), whereas the electric generation based on solar and wind will increase in 18.0% and 11.0%, respectively.

#### 5.4. Final energy consumption

With regard to the final electric energy consumption, distinct scenarios were defined up to the 2040 time horizon, and the calculations were focused on the variables (i) activity level and (ii) energy intensity for each sector, as defined in LEAP, and calculated according Eq. (1).

$$\text{Energy consumption} = \text{Activity level} \times \text{Energy intensity} \quad (1)$$

The results obtained show that, for the Reference scenario, an annual growth rate of 3.4% in final electric energy consumption is expected until 2040, as shown in Table 9. However, for the Intermediate scenario, the growth rate is estimated in the order of 5.6%, thus, higher than the Reference scenario and, in the Efficient scenario, an increase in consumption of 6.8% in relation to the Reference scenario.

**Table 9.** The consumption electricity of all sector and corresponding growth rates (authors' elaboration).

Scenarios' name	Reference	Intermediate	Efficient
Final energy consumption [GWh]	355 129	458 259	512 626
Growth rate [%]/year	3.4	5.6	6.8

The results of the projection of the electrical energy consumption of each sector on Santiago Island are shown in Table 10.

**Table 10.** Disaggregated electricity consumption in each sector on Santiago Island, as given by LEAP.

Sector	Unit	2017	2040		
		(Base year)	Reference	Intermediate	Efficient
Domestic		68 606	181 405	266 232	323 721
Commerce/Industry/Services		44 146	75 349	89 985	91 608
Hotelier		3 963	8 553	8 741	8 706
Public Institutions	[MWh]	15 788	31 355	33 889	33 661
Public Lighting		3 224	6 602	6 714	6 692
Water Desalination		18 931	29 312	31 527	31 308
Thermoelectric Power Plant		5 166	9 833	10 082	10 037
Total Losses		39 464	12 720	11 089	9 893
Total	[MWh]	199 288	355 129	458 259	515 626

#### 5.5. Synthesis of results

Table 11 summarizes the results obtained with LEAP for the years 2017 and 2040 considering the proposed scenarios for Santiago Island. The Intermediate scenario would represent the best estimate in terms of a balanced growth between production and demand for final electric energy.

**Table 11.** Electrical energy system of Santiago Island, as given by LEAP, for the years 2017 and 2040 considering the proposed scenarios.

Indicator	Unit	Base Year - 2017	2040		
			Reference	Intermediate	Efficient
Installed Electrical Production Capacity	Solar PV	[MW]	44.77	101.81	225.04
	Wind		28.72	44.32	103.10
	Diesel		297.29	170.80	96.79
	<i>Total</i>	<i>[MW]</i>	<i>370.78</i>	<i>316.93</i>	<i>424.93</i>
Electrical Energy Generation	Solar PV	[MWh]	4 132	84 134	185 972
	Wind		31 350	148 616	345 673
	Diesel		206 314	364 064	206 314
	<i>Total</i>	<i>MWh</i>	<i>766 989</i>	<i>596 814</i>	<i>737 959</i>
Final Electrical Energy Demand			431 521	578 017	669 254
Final Electrical Energy Consumption	[MWh]	199 288	355 129	458 259	512 626
Total Electrical Energy Losses		39 464	12 720	11 089	9893

### 5.6. Greenhouse gas emissions

In order to analyze the greenhouse gas emissions (GHG) estimates as given by LEAP, two modules have been created associated with the main energy sources, namely lighting and food confection. Table 12 shows the results regarding the GHG emissions resulting from the use of energy.

**Table 12.** Evolution of CO<sub>2eq</sub> emissions in Reference scenario.

	2017	2018	2022	2026	2030	2034	2036	2040
CO <sub>2eq</sub> [metric tonne]	0.325	0.314	0.271	0.228	0.185	0.164	0.121	0.078

## 6. Conclusion

Currently, energy scenarios are instruments of most relevance for achieving sustainable energy planning. From this work, it is concluded that electrical energy consumption on Santiago Island will continue to be mainly in the domestic sector. It is estimated that the domestic segment will represent, on average, around 57.3% of all electrical energy consumption, followed by the commerce/industry/services and public organizations with approximately 19.5% and 7.6%, respectively. With respect to environmental aspects, the scenario Reference shows that there will be a 76.0% reduction in CO<sub>2eq</sub> emissions by 2040. Due to lack of information, as a recommendation for future work, it is suggested the organization of a bank of official information on the energy sector that allows feeding the energy model used, allowing a more complete and detailed analysis of the social, economic and environmental aspects.

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