# Configuring a Photovoltaic Hybrid Plant Considering Future Uncertainty: a Real Options Approach

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## Abstract

Renewable Energy Sources are intermittent in nature. Much more so is Photovoltaic energy, which depending on the project configuration and characteristics, is highly dependent on other sources or storage capacity. This situation makes that configuring a Photovoltaic Hybrid plant, is a matter of operational as well as economic optimization, depending on the situation, regulation and prices at a given moment. We argue in this paper that this optimal configuration can change over time, and that it is highly beneficial to design a plant with flexible complementary hybrid configuration. We use the real options approach to demonstrate this flexibility´s value and apply it to two hypothetical plants in Brazil: one for an agribusiness project in the state of Minas Gerais, and another for a hotel resort in the state of Bahia.

## Introduction

As with other renewable energy plants, the intermittent nature of photovoltaic generation needs the support, or complement, of other easily dispatchable power sources and/or storage technology in order to attend its intended energy delivery goal.

Photovoltaic (PV) generation plants have recently been the power source of choice for isolated, small scale, self-generation, net metering and other generation projects, as well as the adopted pathway for energy transition and decarbonization goals for large firms and corporations. This is due to the versatility, scalability and, of course, price cost reduction in energy units / $ of the PV units. Indeed, among the distributed generation technologies (that produce electricity at or near the consumer, such as residential, commercial or microgrid users, avoiding transmission and distribution losses), the PV generation is an unavoidable player. In the Brazilian scenario, the decentralized generation increased 137% between 2019 and 2020 to reach 5,269 GWh, leaded by the PV technology (the installed capacity more than doubled and generation increasing from 1,659 to 4,764 GWh (+187%) in the same period). This price cost reduction can be compared to that of wind turbines a decade ago, which made of that energy source the renewable energy with largest growth in installed capacity probably worldwide. Nevertheless, PV plants benefit from the versatility of location choice as solar irradiation is much more evenly spread than wind distribution and even in temperate climate countries, with relatively lower irradiation, has been intensely used.

Yet as mentioned, the characteristic intermittence of PV source due to clouds (timescale: second-minute), daily and seasonal cycle irradiation makes it dependent of some sort of complimentary energy source and therefore such plants must be hybrid in nature. This hybrid characteristic can be of several types, dependent on a variety of factors. A very frequent combination is a Wind-PV hybrid plant, since the wind generation during non-irradiation hours can sometimes be sufficient to provide the power load demand across the whole 24 hours day cycle. Other configurations can be more dependent on the PV output capacity and the complimentary scheme destined to provide or store the energy necessary during non-irradiation hours.

As mentioned, designing this last type of hybrid configuration is dependent of a number of factors and combination of these, such as the profile of electricity demand; possibility of grid connection; availability of natural gas supply network; different real time energy tariffs for peak load hour, different price values for grid injected power, etc. The nature of the solar cell (silicon, thin film such as CdTe and CIGS, III-V, organics or perovskites) and the configuration of the array (fixed, one-axis or two-axis tracking PV) are significative technical parameters. An important issue is the possible use of energy storage with batteries or other devices and technologies such as hydrogen production by water electrolysis from PV output. The techno-economical feasibility on such schemes is also dependent on peak load and peak shaving.

However, when some of these characteristics are exogenous (regulation, infrastructure, demand load, energy prices and schemes, etc.) and are already given, then the most efficient type of hybrid configuration is a matter of economic optimization of the better financial performing alternative. What we argue in the present work is that these exogenous points evolve and change with time. As the investment in a PV-plant is a long-term decision (20-25 years), it is possible that the attractiveness of some of the discarded alternatives may change from non-profitable or even non optimal to the best possibility in the future. Therefore, we propose an approach of PV-Hybrid flexible configuration selection that can change or readapt to future uncertainties and maximize economic performance of the project in the long run.

In order to structure the proposed approach, a PV-Hybrid project in Brazil is modeled considering two typical situations of self-generation and all the limits and constrains available to these. We also consider the prices of electricity in several real situations and configurations in order to decide on the most profitable project from a financial investment standpoint. We will also model as stochastic processes the uncertainty variables that affect this result. Then, we will build a Real Options Approach (ROA) to verify the effect of possible configuration change as uncertainties resolve, on the value of the project. As outcome, apart from the economic results, we also will verify statistically the possibility of viability of alternatives that are presently considered unattractive financially.

The present paper will be structured as follows: after this introduction, we will provide a reference on similar or complementary publications that can help understand how this research will be situated in this field of knowledge on the topic. In sequence, we will implement the research already under way on PV-Hybrid plant in Brazil considering the alternatives within the constraints of such plant. Following this, we will develop the cited real options (ROA) model to attain the objectives of the study. Finally, we discuss the results and conclude.

**Literature review**

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**Proposed model**

Photovoltaic generation in Brazil is classified in two different types: Centralized Generation (CG) and Distributed Generation (GD). While the former (CG) is typical of significant corporate investments in large scale units connected to the grid through distribution systems and companies, the latter (DG) is constituted of residential and small business units who generate their own power need and connect to the grid through a net metering platform from which they compensate their excess energy production for use during non-irradiation hours.

Photovoltaic use in Brazil is relatively new when compared to other countries, but the potential is significant in light of the privileged latitude position of its geography. Indeed, Brazil showed a significative PV generation in its electricity matrix only in 2015; while European countries presented a significative share a decade earlier and China and the United States both since 2010. As a consequence, in 2020, Brazil generated 8 TWh of electricity from this renewable source (centralized and distributed generations), while China, Europe and United States generated 261, 179 and 134 TWh, respectively. Therefore, it should be expected that government incentives as well as output performance should be driving the expansion of the photovoltaic capacity. Although this has in fact been happening, at the present moment an abrupt change in regulation regarding the net metering regulation is threatening to reduce the popular interest in PV and therefore significantly diminish the future PV DG installed capacity.

The regulation established in January 2022 (law 14.300/2022) in substitution to the previous norm (REN482/2012), a gradual diminishment in government support was defined for the medium and long run for the existing or validated project and the new rule will be effective in 2029 . Yet this new situation, contrary to what is generally the direction given by governments worldwide, will hamper the development of PV DG development, it is also an opportunity for future development of Energy Storage. While storage costs drop as has been happening, investments , which can in the future turn DG units in independent or isolated units, once in place are beyond the reach of government regulations or incentives.

So designing a plant for a specific project is a matter of performance but also of economic optimization. In this case, lifetime of equipment and capital investment (CapEx) must be taken into account and considered in the investment decision.

This case study starts with the definition of several variables for two PV-Hybrid projects to be implemented in Brazil:

The first project is the energy supply of an agribusiness venture in the State of Minas Gerais at the location of Uberlândia. The typical load demand of such a project can be seen in Figures 1 and 2.

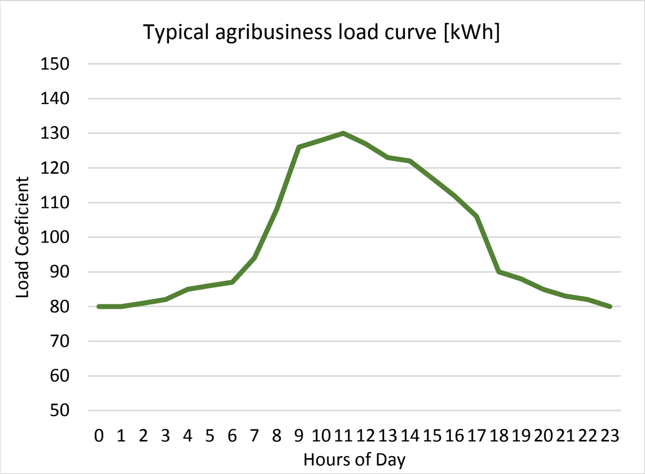


Figure 1 – Agribusiness typical demand curve

Source: Adapted from https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7404915

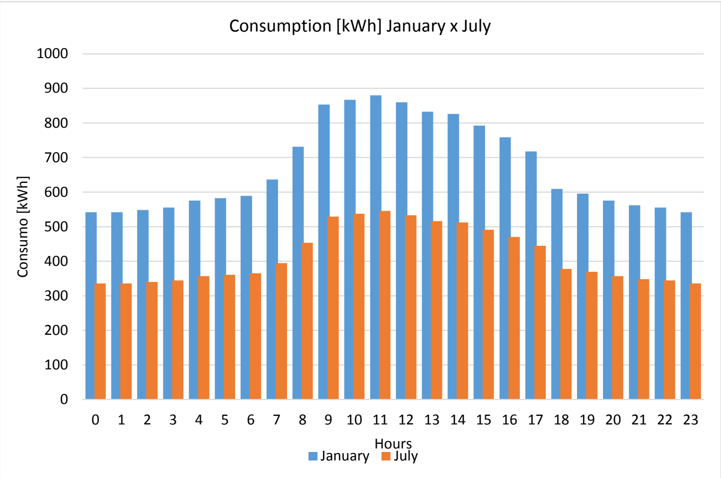


Figure 2 – Agribusiness Energy Consumption January x July

The second project, also located In Brazil, but now of a resort Hotel project in the State of Bahia at Costa do Sauipe. In this case, the typical load demand of a hotel, in summer and winter can be seen in Figure 3.

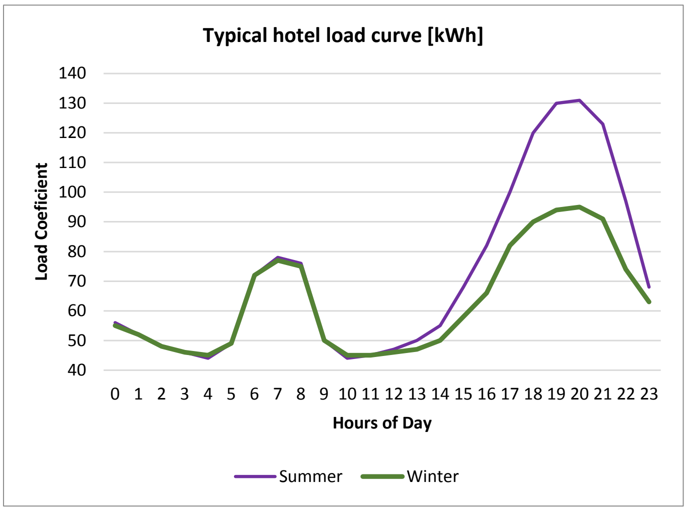


Figure 3 – Hotel Energy Consumption Summer x Winter

For both cases, 36 simulations (detailed in Appendix I) were run for different configurations, considering combination of different factors: net metering, storage (no batteries, 8 batteries, 80 batteries) and secondary power generator (no natural gas genset, natural gas genset of 175kW, natural gas genset of 262kW, natural gas genset of 500 kW – in each case up to two natural gas gensets) – and a flat energy tariff. The same number of cases/ simulations in also to be developed with variable tariff. These configurations are simulated in Homer® software and from which we get the operating profiles depending on the configuration used. With these technical and economic results, we are able to define which solutions for hybrid configuration are more advantageous from a performance as well as economic standpoint.

After these definitions and results, we will move to the forecasting part of our research. We are now able to determine which endogenous variables impact more intensely on the economic results of our choice. From this point, we will model stochastically these variables (energy tariff, battery cost, natural gas tariff, hydrogen price or even impact of new more restrictive regulation on net-metering). The next step will be to model the flexibility to change the configuration of the projects considering the evolution of these important uncertainties.

In order to value the capacity of changing the future design of a PV-Hybrid project, depending on the uncertainties that will be resolved, a Discounted Cash Flow method is not appropriate since it assumes that investment decisions are taken now, and are unchanged by future events, which cannot be presently foreseen. The correct approach for such a project, which is subject to uncertainties, but has the flexibility to change its trajectory in the future if these uncertainties resolve in different than expected ways, is the Real Options Approach (ROA).

The Real Option Approach, or Theory, derived from the work of initially developed by Black and Scholes (1973) and Merton (1973) for financial derivatives pricing as applied to real, rather than financial assets. While real assets are usually priced using discounted cash flow methods, this approach fails to capture the value of flexible real-world decisions, such as the option to anticipate, defer or abandon the construction of a new plant, to expand production, or to switch inputs or outputs. Myers and Majd (1983), Brennan and Schwartz (1985), McDonald and Siegel (1986), and others further developed the basic concepts of this approach and applied it to different types of managerial flexibility. Pindyck (1988), Dixit (1989), Trigeorgis (1995), and Dixit and Pindyck (1994) showed that real options could be useful to evaluate a project under the presence of uncertainty and flexibility for the managers in order to take action on the changes presented to them.

Concerning the valuation of renewable energy projects, there is an extensive literature on the use of the real options approach to this field. Dias et al. (2011) analyzed a sugar and ethanol-producing plant in Brazil which had both the option to expand and to add a cogeneration unit to allow the sale of surplus energy generated by burning sugarcane bagasse, where the existence of the second option was conditional to the exercise of the first option. Brandão, Penedo, and Bastian-Pinto (2011) discussed the value of the input switching options embedded in the production of biodiesel fuel and showed that the choice of model and parameters had a significant impact on the results of the valuation. Dalbem, Brandão, and Gomes (2014) analyzed the option to anticipate the construction of a wind farm plant in order to sell energy in the spot market. They concluded that due to the low price that prevailed at the time, no value was created, which made it unlikely that this option would be exercised. Oliveira et al. (2014) modeled energy prices with mean reversion and jumps using Monte Carlo Simulation for a biomass cogeneration project. For a more detailed discussion of the application of real options to renewable energy projects, we refer the reader to Kozlova (2017) for a comprehensive review of the field, as well as a brief review of real options literature.

WORK IN PROGRESS: MODELING OF REAL OPTIONS

**Results**

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**Discussion**

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**Conclusions**

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**Initially Proposed References**


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**Appendix I**

List of scenarios run for fixed tariff (buy & sell = 1.2 R$/kWh)

| N | Case | Equipments | | | |
|---|---|---|---|---|---|
| 1 | Uberlandia fixed - Agricultural load | Solar | No batteries | No natural gas genset | No natural gas genset |
| 2 | Uberlandia fixed - Agricultural load | Solar | 8 Batteries | No natural gas genset | No natural gas genset |
| 3 | Uberlandia fixed - Agricultural load | Solar | 80 Batteries | No natural gas genset | No natural gas genset |
| 4 | Uberlandia fixed - Agricultural load | Solar | 8 Batteries | natural gas genset 500kW | natural gas genset 500kW |
| 5 | Uberlandia fixed - Agricultural load | Solar | 80 Batteries | natural gas genset 500kW | natural gas genset 500kW |
| 6 | Uberlandia fixed - Agricultural load | Solar | No Batteries | natural gas genset 500kW | natural gas genset 500kW0 |
| 7 | Uberlandia fixed - Agricultural load | Solar | 8 t | natural gas genset 262kW | natural gas genset 175kW |
| 8 | Uberlandia fixed - Agricultural load | Solar | 80 Batteries | natural gas genset 262kW | natural gas genset 175kW |
| 9 | Uberlandia fixed - Agricultural load | Solar | No Batteries | natural gas genset 262kW | natural gas genset 175kW |
| 10 | Uberlandia tracking - Agricultural load | Solar | No Batteries | No natural gas genset | No natural gas genset |
| 11 | Uberlandia tracking - Agricultural load | Solar | 8 Batteries | No natural gas genset | No natural gas genset |
| 12 | Uberlandia tracking - Agricultural load | Solar | 80 Batteries | No natural gas genset | No natural gas genset |
| 13 | Uberlandia tracking - Agricultural load | Solar | 8 Batteries | natural gas genset 500kW | natural gas genset 500kW |
| 14 | Uberlandia tracking - Agricultural load | Solar | 80 Batteries | natural gas genset 500kW | natural gas genset 500kW |
| 15 | Uberlandia tracking - Agricultural load | Solar | No Batteries | natural gas genset 500kW | natural gas genset 500kW |
| 16 | Uberlandia tracking - Agricultural load | Solar | 8 Batteries | natural gas genset 262kW | natural gas genset175kW |
| 17 | Uberlandia tracking - Agricultural load | Solar | 80 Batteries | natural gas genset262kW | natural gas genset175kW |
| 18 | Uberlandia tracking - Agricultural load | Solar | No Batteries | natural gas genset262kW | natural gas genset175kW |
| 19 | Costa do Sauipe fixed - Hotel load | Solar | No Batteries | No natural gas genset | No natural gas genset |
| 20 | Costa do Sauipe fixed - Hotel load | Solar | 8 Batteries | No natural gas genset | No natural gas genset |
| 21 | Costa do Sauipe fixed - Hotel load | Solar | 80 Batteries | No natural gas genset | No natural gas genset |
| 22 | Costa do Sauipe fixed - Hotel load | Solar | 8 Batteries | natural gas genset 500kW | natural gas genset 500kW |
| 23 | Costa do Sauipe fixed - Hotel load | Solar | 80 Batteries | natural gas genset500kW | natural gas genset500kW |
| 24 | Costa do Sauipe fixed - Hotel load | Solar | No Batteries | natura gas genset500kW | natura gas genset500kW |
| 25 | Costa do Sauipe fixed - Hotel load | Solar | 8 Batteries | natura gas genset262kW | natura gas genset175kW |
| 26 | Costa do Sauipe fixed - Hotel load | Solar | 80 Batteries | natura gas genset262kW | natura gas genset175kW |
| 27 | Costa do Sauipe fixed - Hotel load | Solar | No Batteries | natura gas genset262kW | natura gas genset175kW |
| 28 | Costa do Sauipe tracking - Hotel load | Solar | No Batteries | No natura gas genset | No natura gas genset |
| 29 | Costa do Sauipe tracking - Hotel load | Solar | 8 Batteries | No natura gas genset | No natura gas genset |
| 30 | Costa do sauipe tracking - Hotel load | Solar | 80 Batteries | No natura gas genset | No natura gas genset |
| 31 | Costa do sauipe tracking - Hotel load | Solar | 8 Batteries | natura gas genset500kW | natura gas genset500kW |

| | | | | | |
|---|---|---|---|---|---|
| 32 | Costa do sauipe tracking - Hotel load | Solar | 80 Batteries | natura gas genset500kW | natura gas genset500kW |
| 33 | Costa do sauipe tracking - Hotel load | Solar | No Batteries | natura gas genset500kW | natura gas genset500kW |
| 34 | Costa do sauipe tracking - Hotel load | Solar | 8 Batteries | natura gas genset262kW | natura gas genset175kW |
| 35 | Costa do sauipe tracking - Hotel load | Solar | 80 Batteries | natura gas genset262kW | natura gas genset175kW |
| 36 | Costa do sauipe tracking - Hotel load | Solar | No Batteries | natura gas genset262kW | natura gas genset175kW |