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The Energy Storage Systems in Power Systems – A Regulatory View

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Abstract

In this work, a methodology is presented for analyzing the insertion of energy storage systems in electric distribution networks due to different regulatory policies. Various topologies are used as input data, and as output, we have the maximum possible cost that the energy storage system may have to be considered viable by the potential investor. With the input data any combination of 8 regulatory policies are tested, generating 255 scenarios for evaluation. For each scenario, the possible revenue was estimated, with each one of them generating 441 sub-scenarios resulting from the test of several levels of WACC and taxes. Thus, in all, there are more than 100 thousand possible regulatory configurations for evaluation. Based on the calculation of cash flow in each sub-scenario, the work determined the maximum possible cost for each one of them. The proposed method allows the validation of which energy storage technologies are feasible or not, and which technological development they need to achieve considering the regulatory framework in which they are inserted. Through simulations with standard distribution networks using worldwide economical reference values, it is possible to determine which changes regulatory agents must make to enable the rise of storage systems in power distribution networks.

Keywords: Distributed power generation, Economics, Electricity supply industry deregulation, Energy Storage, Power system economics, Profitability

I. INTRODUCTION

IN recent years there has been an expressive increase in resources from renewable generation sources in electric power systems. Many of these sources are by nature intermittent, that is, they have a high variability in the short term, which has represented a new challenge for energy systems. Considering this situation, energy storage systems have emerged initially to support this shortfall. This new scenario has modified the structure, planning and operation of energy systems around the world, changing and inserting new standards or physical elements. In numerous regions of several countries, the levels of renewables have already exceeded the capacity of the transmission and distribution systems, i.e., physically the system does not have the necessary capacity to dispatch these sources, and in this scenario, the most promising solutions include the expansion of systems associated with the concept of smart grids [1].

The challenge would be to limit renewable generation capacity to a maximum value of their total capacity, so as not to expose the system to a risk of collapse due to overloading, voltage or stability constraints. In this way, this has stimulated the development of regulatory frameworks that drive the insertion of energy storage systems (ESS) that could mitigate such restrictions. For network operators, ESSs can offer a number of benefits to the operation of the electric power system, such as reducing peak load and potential overloads, providing reserve power for momentary constraints, improving power quality, demand and among others [2].

In addition, the major benefits ESSs can produce are economic because they are able to improve the utilization rate of energy equipment, provide a lower cost of supply and increase the utilization rate of new power plants. In this way, ESS can be a solution to make the energy market more efficient in competitive markets, since it is able to efficiently allocate consumer and generator surpluses [3].

However, for the expansion of new systems to happen, it is fundamental for the regulatory frameworks to be established in order to consolidate ways of remunerating the ESSs through their services to the system and through their intervention in the electricity market, to conduct price arbitrage in these markets. Thus, the expansion of ESSs depends more on actions of regulatory nature, allowing the rise of these devices in power systems, especially the regulatory standards that include markets to provide all possible services [4].

Although the technology of the storage system in use is important, it is essential to determine the existing regulatory frameworks that will make this system feasible or not.

II. ENERGY STORAGE SYSTEM

A. *Regulatory and Economic View*

The integration of ESS has been the best of the solutions given the expansion of solar and wind energy sources and their intermittent nature, since it is able to assure the necessary stability and quality in electrical energy systems. However, ESSs when evaluated alone are considered expensive and not viable when compared to other solutions, and their attractiveness only tends to increase with the increase of these renewable sources [5].

In this scenario, the benefits of ESSs have been studied and measured as a way of leveraging their use in distribution systems, since they can generate economic and technical benefits. To do so, aspects such as location and dimensioning are objectives to be sought in the installation of ESSs in a distribution system, since they can have a linear relation with the operational profit of these investments. In addition, it is also possible to consider ESSs may be available to distribution system operators to provide some technical support and avoid fluctuations of load and voltage in exchange for some remuneration [6].

In addition to the technical services, ESSs can be used to regulate energy market prices, performing arbitrage in these markets, and can help stimulate renewable sources and discourage thermal systems. In addition, it has been an increasingly viable choice to weigh all the costs involved in merit-based markets. However, even considering only their use for generation, ESSs only tend to become economically viable when they are able to provide ancillary services to the systems making it important to regulate such services [7].

B. Challenges in the insertion of ESSs

The ESS increase in power system, especially in the distribution sector, has generally been limited due to three major problems: low energy market liquidity; changing market conditions; and lack of common standards and procedures to evaluate, connect, operate and maintain ESSs. To mitigate these restrictions, the main recommendations are of the normative and regulatory order of the sector. Such changes are essential to maximize the benefits of ESSs and thus enable their operation, which will only happen if they cost less than the system benefits. However, according to Kloess and Zach [8], revenues from ESSs decreased significantly in the last period, suggesting the need for new regulatory arrangements that reverse this scenario. In this scenario, there are a few possible business models from the perspective of the investor. In this perspective, regulators should seek other possible business models to attract adequately investors, notably three:

i. Cost of service: ESS should receive a fixed remuneration rate based on the amount invested and its operating costs in order to guarantee a minimum return;
ii. Energy market: Possibility to participate in the buying and selling energy market;
iii. Associated with Distributed Generation (DG): functioning exclusively as a complementary device and support to the DGs.

Moreno [9] indicate the best configuration would be the combination of the current classic models, allowing ESS to provide multi-service and energy market performance, maximizing its revenues and making new investments easier, but only if such changes are associated with changes within the current regulatory framework. It is considered that all the benefits that the ESSs provide to the system could be remunerated, such as: reduction of the load peak, reduction of the total system operation cost, reduction of the generation cost, more efficient use of the generation system, impacts on energy market prices, among others.

There are also studies indicating that far beyond these technical aspects, which would be the price of energy and the number of hours of operation of the ESS, are in fact the factors with the greatest influence on revenue, both factors interconnected to the energy market, these factors being the highest risk to existing business models for ESS expansion. Given this scenario of uncertainties, the need for regulatory agents to address the issue is increasingly important, with at least six points being essential [10]:

i. Appropriate project return rate;
ii. Opening of ancillary services markets;
iii. Ensuring clear and adequate standards for connecting ESSs to power systems;
iv. Access to the energy market;
v. Consider ESSs as part of the solution in planning distribution systems;
vi. Regulations to ensure proper supervision of ESSs and their operational safety.

There are also other aspects that regulators do not have direct influence, but can be treated or considered in their current regulatory standards, such as capital costs, operating and maintenance costs, storage capacity factor, technology efficiency, financing, government incentives, among others. And there are also important aspects that depend more on investor choice, but they should be considered in the regulatory framework, such as the location and size of the ESS, since from this the impacts on power systems and energy markets will be important items in the modeling regulatory and such choices are dynamic [11].

Finally, in many aspects the technological maturity of ESSs has not yet been reached, which costs can still be high, creating a difficulty in finding a minimum return for the investor, and it may be necessary to establish some public policy contributions, until technological maturity is reached [12].

III. METHODOLOGY AND PROBLEM FORMULATION

The purpose is to evaluate how to create a favorable environment for the implementation of ESS in distribution networks in function of the existing regulatory arrangements. The challenge is to determine how to conduct this assessment in a comprehensive way through standard distribution networks and known and possible regulatory policies.

The proposal is to evaluate several possible scenarios based on pre-defined networks by changing:

- Regulatory Policy: the existence or not of a specific regulatory standard in the sector;
- Economic attractiveness: Many levels of cost of capital;
- Taxes: several net tax rates;
- Prices: various prices in the energy market;
- Load: several daily and annual load scenarios;
- Generation: several scenarios of generation;
- Technologies: Investments and operation costs of ESSs.

All evaluations consider the electrical restraints of the ESS operation

A. *Restrictions for ESS Operation*

1) *Voltage Level*

Analysis of voltage increase at the time of ESS discharge and of under voltage in ESS loading according to (1)

$$V_{iSAE} = \left\{ \begin{matrix} V_{min} \leq V_{iESS} \leq V_{imax}, \ \ se\ V_{min} \leq V_i \leq V_{imax} \\ V_i \leq V_{iESS} \leq V_{imax}, \ \ se\ V_i < V_{min} \\ V_{min} \leq V_{iESS} \leq V_i, \ \ se\ V_{max} < V_i \end{matrix} \right\} \quad (1)$$

Where

V_{iESS} = voltage on bus i after ESS installation;

V_i = voltage on bus i in the original system;

V_{min} = minimum regulatory voltage;

V_{max} = maximum regulatory voltage.

2) *Loading*

Analysis of the system loading, in the ESS load there will be an increase in the loading of the system according to (2).

$$L_{SAE} = \left\{ \begin{matrix} L_{ESS\_i} \leq L_{CL\_i}, \ \ if\ L_{original\_i} \leq L_{CL\_i} \\ L_{ESS\_i} \leq L_{original\_i}, \ \ if\ L_{CL\_i} < L_{original\_i} \end{matrix} \right\} \quad (2)$$

Where

L_{ESS} = loading of the line i during the charging period;

L_{CL} = line limit capacity i;

$L_{original}$ = original loading in line i.

B. *Regulatory Policies*

1) *Loading*

Service provided by the ESS to reduce peak loads in the system and thus eliminate overloads according to (3).

$$FI_{Load} = Cf_{load} \sum_{p=1}^{P} \sum_{t=1}^{T} (\Delta Pot^D ESS(p,t)\ Tu^D ESS(p,t)) \quad (3)$$

Where:

FI_{load} = financial income from the service avoided peak load;

Cf_{load} = avoided peak load operation coefficient;

P = demand peaks eliminated;

$\Delta Pot^D ESS(p,t)$ = reduced demand value on ESS discharge at time t;

$Tu^D ESS(p,t)$ = time of discharging at time t.

2) *System Expansion*

Service provided by ESS to postpone system expansion investments according to (4).

$$FI_{exp} = \left[Cfexp \sum_{p=1}^{P} \sum_{t=1}^{T} (\Delta Pot^D ESS(p,t)\ Tu^D ESS(p,t))) \times (1 + WACC_R)^N \right] \quad (4)$$

Where:

FI_{exp} = financial income from the service of postpone system expansion;

Cf_{exp} = coefficient of expansion over the peak of avoided load (it will be determined by the cost of the postponed);

$WACC_R$= regulatory WACC (weighted average cost of capital) recognized by the regulatory agency;

N = number of years of expansion has been postponed.

3) *Losses*

Service provided to reduce system losses according to (5).

$$FI_{Loss} = CfLoss \sum_{t=1}^{T} max\{\Delta Loss^D ESS(t)\}\ \mathrm{Pr}^D \mathrm{ESS} - min\{\Delta Loss^L ESS(t)\} \mathrm{Pr}^L \mathrm{ESS} \quad (5)$$

Where:

FI_{Loss} = financial income from the service loss reduction;

Cf_{Loss} = coefficient of reduced losses;

$\Delta Loss^D ESS(t)$ = loss reduction with ESS discharge;

$\mathrm{Pr}^D \mathrm{ESS}$ = energy price during the ESS discharge;

$\Delta Loss^L ESS(t)$ = increased losses with the ESS loading;

$\mathrm{Pr}^L \mathrm{ESS}$ = energy price during the ESS loading;

4) *Reactive*

Service provided by the ESS for absorption or injection of reactive power in the system according to (6).

$$FI_{React} = \sum_{t=1}^{T} \left(Cq_{ind(t)}\ \lambda_q^{ind}) + (Cq_{cap(t)}\ \lambda_q^{cap}) \right) \quad (6)$$

Where:

FI_{React} = financial income from the service reactive;

Cq_{ind} = ESS inductive reactive compensation;

Cq_{cap} = ESS capacitive reactive compensation;

λ_q^{ind} = cost of reactive absorption;

λ_q^{cap} = cost of reactive injection.

5) *Penalties*

Considering the benefits and services that the ESS can promote to the system, it is important to guarantee incentives so that it is available as long as possible and one way is to penalize its unavailability according to (7).

$$Pen_{Unav} = \sum_{t=1}^{T} Cfunav \left[\left(Pot_{up}^{Res}(t) - Pot_{up}^{atual}(t) \right) - \left(Pot_{down}^{Res}(t) - Pot_{down}^{atual}(t) \right) \right] \times (\Delta u(t)\ \lambda \sec(t)) \quad (7)$$

Where:

Pen_{Unav} = cost of penalty for ESS unavailability;

Cf_{unav} = penalty coefficient of unavailability;

$\left(Pot_{up}^{Res}(t) - Pot_{up}^{atual}(t)\right) - \left(Pot_{down}^{Res}(t) - Pot_{down}^{atual}(t)\right)$= difference between the required and the available capacity of ESS;

Δu = proportion of unavailable ESS time;

λsec = energy price in the secondary market.

6) Penalties

The ESS will exclusively serve a generating system, when it is expected and negotiated generation in the market is inferior to what is actually generated, according to (8).

$$FI_{SGer} = \sum_{t}^{T} \left(Pot_{ren}^{Exp} - Pot_{ren}^{Real}\right) \lambda spot \qquad (8)$$

if (9) is true:

$$Pot_{ren}^{Exp} < Pot_{ren}^{Real} \qquad (9)$$

Where:

FI$_{SGer}$ = financial income from the service to support the generation;

Pot_{ren}^{Exp} = expected generation power;

Pot_{ren}^{Real} = real generation power output;

λspot = spot market price of energy.

7) General System Support

It is also possible to provide the same load-supply service for the entire system, according to (10).

$$\begin{aligned} FI_{SSyst} = \sum_{t=1}^{T} \Big(Pot_{up}^{Res}(t) \\ + Pot_{down}^{Res}(t)\Big) \lambda \sec(t)\, CfSys \\ - \sum_{t=1}^{T} Pot_{up}^{Res}(t)\lambda_{up}^{ter}(t) \\ + \sum_{t=1}^{T} Pot_{down}^{Res}(t)\lambda_{down}^{ter}(t) \end{aligned} \qquad (10)$$

Where:

FI$_{SSyst}$ = financial income from the service to support the system;

Cf$_{Sys}$ = service coefficient to support the system;

Pot_{up}^{Res} = excess power in the system, ESS absorbs power;

Pot_{down}^{Res} = power deficit in the system, ESS injects power;

Λsec = energy price in the secondary market;

λ_{up}^{ter} = price of energy in the tertiary or secondary upstream market;

λ_{down}^{ter} = price of energy in the tertiary or secondary downstream market.

8) Primary Energy Market

Finally, it is necessary to account for its injected and received energy according to the hourly market of the period and moment used, according to (11). This intervention may be the result of previous interventions or only to perform arbitrage in the energy market, i.e., absorbing energy with low prices and injecting energy with high prices.

$$\begin{aligned} FI_{Mark} = \sum_{t=1}^{T} [Pr^{D}ESS(t)Tu^{D}ESS(t)] \\ - [Pr^{L}ESS(t)\, Tu^{L}ESS(t)] \end{aligned} \qquad (11)$$

Where:

FI$_{Mark}$ = financial income from the arbitrage in the energy market;

$Pr^{D}ESS$ = energy price in discharge time t;

$Tu^{D}ESS$ = discharge period used at time t;

$Pr^{L}ESS$ = energy price in loading time t;

$Tu^{L}ESS$ = loading period used at time t.

C. Model of Possible Income

The final model should consider all constraints and returns on each service provided by the ESS to the system or in the energy market. Thus, the total return will be according to (12).

$$\begin{aligned} FI_{(t)} = FI_{Load} + FI_{exp} + FI_{Loss} + FI_{React} \\ - Pen_{Unav} + FI_{SGer} + FI_{SSyst} \\ + FI_{Mark} \end{aligned} \qquad (12)$$

Where:

FI$_{(t)}$ = possible total financial income of the ESS

An analysis of the regulatory framework under evaluation should be included, whether each item is provided by current legislation or not. A regulatory framework can be defined as:

- μ$_{Load}$ = regulatory standard for load reduction service;
- μ$_{exp}$ = regulatory standard for postponement expansion investments service;
- μ$_{Loss}$ = regulatory standard for loss reduction service;
- μ$_{React}$ = regulatory standard for reactive compensation service;
- μ$_{Pen}$ = regulatory standard to penalize the ESS unavailability;
- μ$_{SGer}$ = regulatory standard for supporting power generation service;
- μ$_{SSyst}$ = regulatory standard for supporting system service;
- μ$_{Mark}$ = regulatory standard allowing the existence of an hourly market.

Defining each μ as 1 or 0, when the regulation exists or not, respectively. In this way, the model accords (13):

$$F_{(t)} = (\mu_{Load} FI_{Load}) + (\mu_{exp} FI_{exp}) + (\mu_{Loss} FI_{Loss}) + (\mu_{React} FI_{React}) - (\mu_{Pen} Pen_{Unav}) + (\mu_{SGer} FI_{SGer}) + (\mu_{SSyst} FI_{SSyst}) + (\mu_{Mark} FI_{Mark}) \quad (13)$$

Subject to the voltage and loading restrictions presented.

Several scenarios will be defined, from one where there is only one existing policy to one in which all possible policies will be in place. Considering 8 possible regulatory standards there are 255 combinations of possible regulatory scenarios in each simulation.

D. Investment Model

The investment model should consider ESS investment and operating costs, capital costs, tax rate and a financial viability analysis.

1) ESS Costs

The ESS costs are based on initial investment and their costs for operation and maintenance, which will vary depending on the maximum load and discharge capacity and their energy storage capacity (14).

$$C_{Total} = min\{C_{Inv} + C_{Op}\} \quad (14)$$

Where:

C_{Total} = ESS total cost;

C_{Inv} = initial investment cost;

C_{Op} = annual cost of operation and maintenance;

The total cost will depend on the size of the ESS, but the references used are the costs per kW and per kWh.

2) WACC

The WACC is the capital cost of a company to make the necessary investments in its business. For non-regulated sectors, the reference value will depend on the capital structure of each company and may change significantly. For regulated sectors the same evaluation is used, but the average cost of the sector is considered.

The perception of market risk is considered more accentuated and not so objective for new businesses in a sector with very premature regulation, thus causing a significant increase in its WACC. Therefore, given the interdependence of the WACC value with external factors and often with interference by the very limited regulator, this value will be modified and tested at several levels, because depending on the level of risk associated with the construction and operation business of ESSs the value of WACC may vary considerably.

3) Tax Rate

The tax rate on ESS operations is also an important item because, in addition to the high variability between regions, it can be the crucial item to enable ESS operation, and also be an item of attention to regulator agents.

The final marginal tax on the financial operations of ESS is considered in this study and is evaluated according to (15).

$$FI_{Real\,(t)} = (1 - Tax)FI_{(t)} \quad (15)$$

Where:

FI_{Real} = adjusted annual financial income;

Tax = marginal tax on ESS operations;

$FI_{(t)}$ = annual financial income of the ESS.

4) Possible Maximum Investment

Investment analysis can be performed by several methods, one of the most common being through the Internal Rate of Return (IRR) of the project, which is used to calculate the discount rate that a cash flow must have so that its Net Present Value (NPV) is equal to zero. An appropriate IRR is one that is equal to or greater than the Minimum acceptable Rate of Return (MRR), that represents the minimum return an investor accepts to own an investment. For regulated sectors, the MRR can be defined as the regulatory WACC of sector, which is defined by the regulatory agency. Otherwise, this analysis can be done according to (16).

$$NPV = 0 = -C_{Inv} + \sum_{t=1}^{N} \frac{FI_{Real\,(t)}}{(1 + IRR)^t} \quad (16)$$

Where:

NPV = net present value;

C_{Inv} = initial investment cost;

IRR = internal rate of return or regulatory WACC;

N = number of years in operation;

FI_{Real} = adjusted annual financial income.

The goal is to determine a possible investment considering a WACC value and the defined financial income for each regulatory scenario. Thus, the response for each evaluation will be a maximum investment value according (19).

$$C_{Inv} = \sum_{t=1}^{N} \frac{FI_{Real\,(t)}}{(1 + IRR)^t} \quad (19)$$

Thus, the maximum possible investment value is determined, which means that for any investment value above this value the business will become non-viable and any value below this limit will produce positive results.

Therefore, considering the proposed regulatory framework in which there is no violation of any restriction and based on several WACC values and tax rate on the total financial income, it is possible to determine in which scenarios the ESS installation will be viable or not.

5) Regulatory and Financial References

International regulatory and financial references were used and the most common references regarding public policies and public values are from the EPRI (Electric Power Research Institute) and DOE USA (US Department of Energy) and the references of price in energy market were obtained from California - USA. The values of these regulatory references are presented in Table 1 according to [13, 14]:

TABLE I.

Item	***Reference***
Reduce peak loads	37.00 US$/kW per year
Postpone investments	43.75 US$/kW per year and WACC 4%
Reduce losses	50% mean price of 28,359 US$/MWh
Absorption reactive	2.63 US$/kvar per year
Penalties	1.00 US$/kWh per unavailability
Generation Support	75.79 US$/kW per year
System Support	21.72 US$/kW per year in normal system and 79.92 US$/kW in overload system 70.88 US$/kW per year in long term
Market energy	Load in the minimum price and discharge in the maximum price, for 80% of the days in operation and efficiency of 90%

IV. DATA AND CASE STUDY

The case study to analyze the regulatory framework for insertion of ESSs is carried out to determine which are the regulatory policies and which combinations of these can be more significant and can further promote these types of assets in distribution systems.

The evaluation is performed based on the proposed methodology and regulatory reference values presented and based on the standard system of energy distribution called IEEE 34 bus. For the simulations, the OpenDSS computational tool associated to Matlab is used. Assumptions are done based on technical references and these references are presented in Tables II and III.

TABLE II. TECHNICAL ASSUMPTIONS

Item	***Reference***
Efficiency	95% in discharge and 90% in load
Dimension	100 kW (power) and 100 kWh (energy)
Location	In the bus with greater reduction of losses
Time per year	80% days of the year
Time per day	1h in load e 1h in discharge scheduled
Unavailability	4 unscheduled interruptions per year
Generation Support	30 minutes per day in 50% days of the year
System Support	20 minutes per day in 100% days of the year

TABLE III. ECONOMICS ASSUMPTIONS

Item	***Reference***
Life cycle	15 years
Operation Cost	2% of initial investment per year
Replacement Cost	30% of initial investment in all life cycle
Microeconomics	ESSs do not influence the market price
Profit	10% of remuneration per year
WACC	Variations from 0% to 20%
Tax	Variations from 0% to 40%
Load growth	4% per year
Load curve	Based on California market energy

V. RESULTS AND DISCUSSION

A. Simulations

The simulations correspond to the evaluation of each one of all possible combinations of the regulatory policies evaluated and described in Table IV, promoting in all 255 scenarios.

TABLE IV. REGULATORY POLICIES

ID	***Regulatory Policy (Services Provided)***
1	Reduce peak loads
2	Postpone investments
3	Reduce losses
4	Absorption reactive
5	Penalties
6	Generation Support
7	System Support
8	Market energy Arbitrage

For each of the 255 scenarios, it created other sub scenarios where it was tested the WACC variation and the tax rate, providing for each scenario another 441 sub scenarios for evaluation, in this way, there were more than 100 thousands possible sub scenarios for evaluation. For reference of feasibility of investments two limits were adopted that would allow the installation of ESS:

- Limit 1: Values that would allow the installation of mature technologies, with a reference value of 900 US$ per 1 kW of power and 1 kWh of storage;

- Limit 2: Values that could enable non-commercial technologies, with a reference value of US$ 2,000 per 1 kW of power and 1 kWh of storage;

The result of each scenario is illustrated in Table VI.

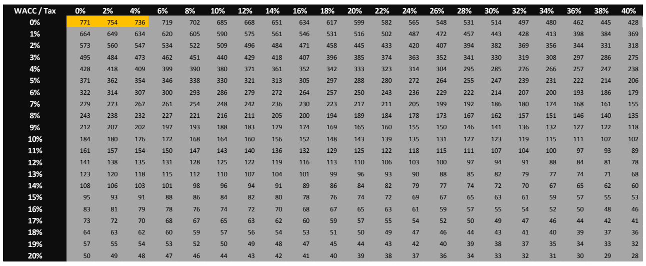
TABLE V. IDENTIFICATION OF RESULTS

Code	***Evaluation***
🟩	Value above Limit 1 and Limit 2 Allows installation of non-commercial and mature technologies
🟦	Value above only limit 1 Allows installation just of commercial technologies
🟨	Value at 80% of Limit 1 value New technological advances in cost-effectiveness may allow commercial technologies
▒	Values make any technology unfeasible

In the following items, the most promising result of the evaluated scenarios is presented, that is, the one that allows a greater amount of sub scenarios under analysis.

B. *Scenarios with Only One Policy in Operation*

The highlight is in the application of policy 8, which, although it did not obtain an adequate response, presented values at 80% of this limit as shown below. In this scenario, there are 3 sub scenarios in this category, which occur when the WACC is equal to zero and the tax rate varies up to a maximum of 4% per year, as can be seen in Fig. 1.

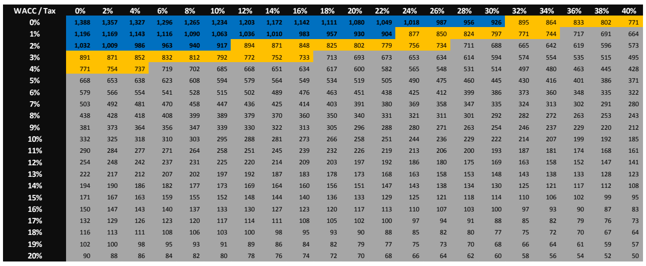


WACC / Tax	0%	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%	32%	34%	36%	38%	40%
0%	771	754	736	719	702	685	668	651	634	617	599	582	565	548	531	514	497	480	462	445	428
1%	664	649	634	620	605	590	575	561	546	531	516	502	487	472	457	443	428	413	398	384	369
2%	573	560	547	534	522	509	496	484	471	458	445	433	420	407	394	382	369	356	344	331	318
3%	495	484	473	462	451	440	429	418	407	396	385	374	363	352	341	330	319	308	297	286	275
4%	428	418	409	399	390	380	371	361	352	342	333	323	314	304	295	285	276	266	257	247	238
5%	371	362	354	346	338	330	321	313	305	297	288	280	272	264	255	247	239	231	222	214	206
6%	322	314	307	300	293	286	279	272	264	257	250	243	236	229	222	214	207	200	193	186	179
7%	279	273	267	261	254	248	242	236	230	223	217	211	205	199	192	186	180	174	168	161	155
8%	243	238	232	227	221	216	211	205	200	194	189	184	178	173	167	162	157	151	146	140	135
9%	212	207	202	197	193	188	183	179	174	169	165	160	155	150	146	141	136	132	127	122	118
10%	184	180	176	172	168	164	160	156	152	148	143	139	135	131	127	123	119	115	111	107	102
11%	161	157	154	150	147	143	140	136	132	129	125	122	118	115	111	107	104	100	97	93	89
12%	141	138	135	131	128	125	122	119	116	113	110	106	103	100	97	94	91	88	84	81	78
13%	123	120	118	115	112	110	107	104	101	99	96	93	90	88	85	82	79	77	74	71	68
14%	108	106	103	101	98	96	94	91	89	86	84	82	79	77	74	72	70	67	65	62	60
15%	95	93	91	88	86	84	82	80	78	76	74	72	69	67	65	63	61	59	57	55	53
16%	83	81	79	78	76	74	72	70	68	67	65	63	61	59	57	55	54	52	50	48	46
17%	73	72	70	68	67	65	63	62	60	59	57	55	54	52	50	49	47	46	44	42	41
18%	64	63	62	60	59	57	56	54	53	51	50	49	47	46	44	43	41	40	39	37	36
19%	57	55	54	53	52	50	49	48	47	45	44	43	42	40	39	38	37	35	34	33	32
20%	50	49	48	47	46	44	43	42	41	40	39	38	37	36	34	33	32	31	30	29	28

Fig. 1. Application of Regulatory Policy 8

C. *Scenarios with Two Policies in Operation*

In applying two regulatory policies at the same time, there are 28 possible scenarios. In these combinations it is possible to verify that in 8 scenarios there is at least one sub-scenario above limit 1 only and another 5 scenarios are above 80% of this limit 1. The most promising scenario corresponds to the regulatory arrangement composed by the association of regulatory policies 6 and 8, and in this scenario there are 34 sub scenarios that allow investment above limit 1, which occur for a WACC between 0% and 2% and taxation from 0% to 30% according to Fig. 2.



WACC / Tax	0%	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%	32%	34%	36%	38%	40%
0%	1,388	1,357	1,327	1,296	1,265	1,234	1,203	1,172	1,142	1,111	1,080	1,049	1,018	987	956	926	895	864	833	802	771
1%	1,196	1,169	1,143	1,116	1,090	1,063	1,036	1,010	983	957	930	904	877	850	824	797	771	744	717	691	664
2%	1,032	1,009	986	963	940	917	894	871	848	825	802	779	756	734	711	688	665	642	619	596	573
3%	891	871	852	832	812	792	772	752	733	713	693	673	653	634	614	594	574	554	535	515	495
4%	771	754	737	719	702	685	668	651	634	617	600	582	565	548	531	514	497	480	463	445	428
5%	668	653	638	623	608	594	579	564	549	534	519	505	490	475	460	445	430	416	401	386	371
6%	579	566	554	541	528	515	502	489	476	463	451	438	425	412	399	386	373	360	348	335	322
7%	503	492	481	470	458	447	436	425	414	403	391	380	369	358	347	335	324	313	302	291	280
8%	438	428	418	408	399	389	379	370	360	350	340	331	321	311	301	292	282	272	263	253	243
9%	381	373	364	356	347	339	330	322	313	305	296	288	280	271	263	254	246	237	229	220	212
10%	332	325	318	310	303	295	288	281	273	266	258	251	244	236	229	222	214	207	199	192	185
11%	290	284	277	271	264	258	251	245	239	232	226	219	213	206	200	193	187	181	174	168	161
12%	254	248	242	237	231	225	220	214	209	203	197	192	186	180	175	169	163	158	152	147	141
13%	222	217	212	207	202	197	192	187	183	178	173	168	163	158	153	148	143	138	133	128	123
14%	194	190	186	182	177	173	169	164	160	156	151	147	143	138	134	130	125	121	117	112	108
15%	171	167	163	159	155	152	148	144	140	136	133	129	125	121	118	114	110	106	102	99	95
16%	150	147	143	140	137	133	130	127	123	120	117	113	110	107	103	100	97	93	90	87	83
17%	132	129	126	123	120	117	114	111	108	105	102	100	97	94	91	88	85	82	79	76	73
18%	116	113	111	108	106	103	100	98	95	93	90	88	85	82	80	77	75	72	70	67	64
19%	102	100	98	95	93	91	89	86	84	82	79	77	75	73	70	68	66	64	61	59	57
20%	90	88	86	84	82	80	78	76	74	72	70	68	66	64	62	60	58	56	54	52	50

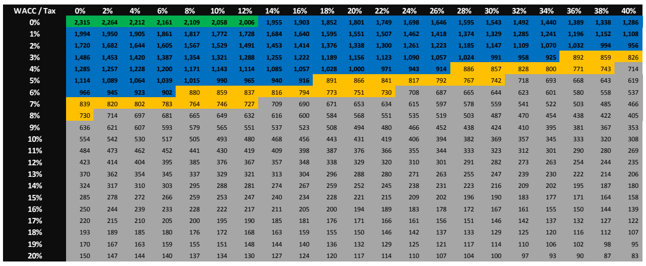
Fig. 2. Application of Regulatory Policy 6 and 8

D. *5.4 Scenarios with three or four Policies in Operation*

With three policies, the most promising scenario is what combines the 6, 7 and 8 regulatory policies, since in this scenario there are 74 sub scenarios that allow investments above the limit 1, which can be between 0% and 4% WACC and 40%, but there are not still scenarios above limit 2.

With the application of four regulatory policies at the same time, there are 70 possible scenarios. From this moment on, it is possible to verify that there are three scenarios where there is viable investments above limit 2, that is, scenarios that could make viable beyond commercial technologies, those in the phase of maturing. In addition, there are 54 more scenarios with viability above the limit 1 and another 9 above 80% of this limit 1.

The most promising scenario combines policies 2, 6, 7 and 8, where there are 7 possible sub-scenarios above limit 2, considering a WACC of 0% and taxation of up to 12%. At the same time, there are still 101 sub-scenarios that allow investments above limit 1, considering a WACC of up to 6% and taxation up to the 40% limit analyzed. Already for investments above 80% of limit 1 it is possible to sub-scenarios with WACC of up to 8%, according to Fig. 3.



WACC / Tax	0%	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%	32%	34%	36%	38%	40%
0%	2,315	2,264	2,212	2,161	2,109	2,058	2,006	1,955	1,903	1,852	1,801	1,749	1,698	1,646	1,595	1,543	1,492	1,440	1,389	1,338	1,286
1%	1,994	1,950	1,905	1,861	1,817	1,772	1,728	1,684	1,640	1,595	1,551	1,507	1,462	1,418	1,374	1,329	1,285	1,241	1,196	1,152	1,108
2%	1,720	1,682	1,644	1,605	1,567	1,529	1,491	1,453	1,414	1,376	1,338	1,300	1,261	1,223	1,185	1,147	1,109	1,070	1,032	994	956
3%	1,486	1,453	1,420	1,387	1,354	1,321	1,288	1,255	1,222	1,189	1,156	1,123	1,090	1,057	1,024	991	958	925	892	859	826
4%	1,285	1,257	1,228	1,200	1,171	1,143	1,114	1,085	1,057	1,028	1,000	971	943	914	886	857	828	800	771	743	714
5%	1,114	1,089	1,064	1,039	1,015	990	965	940	916	891	866	841	817	792	767	742	718	693	668	643	619
6%	966	945	923	902	880	859	837	816	794	773	751	730	708	687	665	644	623	601	580	558	537
7%	839	820	802	783	764	746	727	709	690	671	653	634	615	597	578	559	541	522	503	485	466
8%	730	714	697	681	665	649	632	616	600	584	568	551	535	519	503	487	470	454	438	422	405
9%	636	621	607	593	579	565	551	537	523	508	494	480	466	452	438	424	410	395	381	367	353
10%	554	542	530	517	505	493	480	468	456	443	431	419	406	394	382	369	357	345	333	320	308
11%	484	473	462	452	441	430	419	409	398	387	376	366	355	344	333	323	312	301	290	280	269
12%	423	414	404	395	385	376	367	357	348	338	329	320	310	301	291	282	273	263	254	244	235
13%	370	362	354	345	337	329	321	313	304	296	288	280	271	263	255	247	239	230	222	214	206
14%	324	317	310	303	295	288	281	274	267	259	252	245	238	231	223	216	209	202	195	187	180
15%	285	278	272	266	259	253	247	240	234	228	221	215	209	202	196	190	183	177	171	164	158
16%	250	244	239	233	228	222	217	211	205	200	194	189	183	178	172	167	161	155	150	144	139
17%	220	215	210	205	200	195	190	185	181	176	171	166	161	156	151	146	142	137	132	127	122
18%	193	189	185	180	176	172	168	163	159	155	150	146	142	137	133	129	125	120	116	112	107
19%	170	167	163	159	155	151	148	144	140	136	132	129	125	121	117	114	110	106	102	98	95
20%	150	147	144	140	137	134	130	127	124	120	117	114	110	107	104	100	97	93	90	87	83

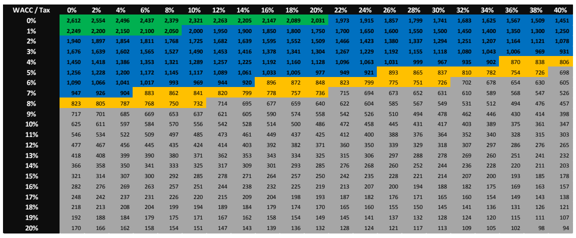
Fig. 3. Application of Regulatory Policy 2, 6, 7 and 8

E. *5.5 Scenarios with five or more Policies in Operation*

With five regulatory policies at the same time, there are altogether 56 possible scenarios. In these combinations it is possible to verify that there are 11 scenarios that enable the second investment limit, besides 43 scenarios with viable above limit 1 and additionally 2 scenarios only above 80% of limit 1.

Among these scenarios, the most promising is one that combines regulatory policies 1, 2, 6, 7 and 8, because in this scenario there are 16 possible sub scenarios above limit 2, considering a WACC of up to 1% and a taxation up to 20%.

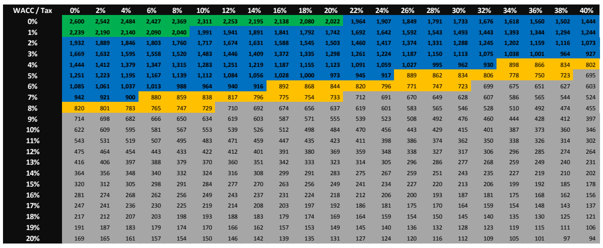
There are also 110 sub-scenarios that allow investments above limit 1, with a WACC of up to 7% and taxation up to the 40% limit analyzed. Already for investments above 80% of limit 1 it is possible to have sub-scenarios with WACC of up to 8%, according to Figure 4.



WACC / Tax	0%	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%	32%	34%	36%	38%	40%
0%	2,612	2,554	2,496	2,437	2,379	2,321	2,263	2,205	2,147	2,089	2,031	1,973	1,915	1,857	1,799	1,741	1,683	1,625	1,567	1,509	1,451
1%	2,249	2,200	2,150	2,100	2,050	2,000	1,950	1,900	1,850	1,800	1,750	1,700	1,650	1,600	1,550	1,500	1,450	1,400	1,350	1,300	1,250
2%	1,940	1,897	1,854	1,811	1,768	1,725	1,682	1,639	1,595	1,552	1,509	1,466	1,423	1,380	1,337	1,294	1,251	1,207	1,164	1,121	1,078
3%	1,676	1,639	1,602	1,565	1,527	1,490	1,453	1,416	1,378	1,341	1,304	1,267	1,229	1,192	1,155	1,118	1,080	1,043	1,006	969	931
4%	1,450	1,418	1,386	1,353	1,321	1,289	1,257	1,225	1,192	1,160	1,128	1,096	1,063	1,031	999	967	935	902	870	838	806
5%	1,256	1,228	1,200	1,172	1,145	1,117	1,089	1,061	1,033	1,005	977	949	921	893	865	837	810	782	754	726	698
6%	1,090	1,066	1,041	1,017	993	969	944	920	896	872	848	823	799	775	751	726	702	678	654	630	605
7%	947	926	904	883	862	841	820	799	778	757	736	715	694	673	652	631	610	589	568	547	526
8%	823	805	787	768	750	732	714	695	677	659	640	622	604	585	567	549	531	512	494	476	457
9%	717	701	685	669	653	637	621	605	590	574	558	542	526	510	494	478	462	446	430	414	398
10%	625	611	597	584	570	556	542	528	514	500	486	472	458	445	431	417	403	389	375	361	347
11%	546	534	522	509	497	485	473	461	449	437	425	412	400	388	376	364	352	340	328	315	303
12%	477	467	456	445	435	424	414	403	392	382	371	360	350	339	329	318	307	297	286	276	265
13%	418	408	399	390	380	371	362	353	343	334	325	315	306	297	288	278	269	260	251	241	232
14%	366	358	350	341	333	325	317	309	301	293	285	276	268	260	252	244	236	228	220	211	203
15%	321	314	307	300	292	285	278	271	264	257	250	242	235	228	221	214	207	200	193	185	178
16%	282	276	269	263	257	251	244	238	232	225	219	213	207	200	194	188	182	175	169	163	157
17%	248	242	237	231	226	220	215	209	204	198	193	187	182	176	171	165	160	154	149	143	138
18%	218	213	208	204	199	194	189	184	179	174	170	165	160	155	150	145	141	136	131	126	121
19%	192	188	184	179	175	171	167	162	158	154	149	145	141	137	132	128	124	120	115	111	107
20%	170	166	162	158	154	151	147	143	139	136	132	128	124	121	117	113	109	105	102	98	94

Fig. 4. Application of Regulatory Policy 1, 2, 6, 7 and 8

In the application of more than 5 five policies the increase is marginal, being that with all 8 regulatory policies at the same time it is possible to verify the possibility of installing ESSs as illustrated in Figure 5.



WACC / Tax	0%	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%	32%	34%	36%	38%	40%
0%	2,600	2,542	2,484	2,427	2,369	2,311	2,253	2,195	2,138	2,080	2,022	1,964	1,907	1,849	1,791	1,733	1,676	1,618	1,560	1,502	1,444
1%	2,239	2,190	2,140	2,090	2,040	1,991	1,941	1,891	1,841	1,792	1,742	1,692	1,642	1,592	1,543	1,493	1,443	1,393	1,344	1,294	1,244
2%	1,932	1,889	1,846	1,803	1,760	1,717	1,674	1,631	1,588	1,545	1,503	1,460	1,417	1,374	1,331	1,288	1,245	1,202	1,159	1,116	1,073
3%	1,669	1,632	1,595	1,558	1,520	1,483	1,446	1,409	1,372	1,335	1,298	1,261	1,224	1,187	1,150	1,113	1,075	1,038	1,001	964	927
4%	1,444	1,412	1,379	1,347	1,315	1,283	1,251	1,219	1,187	1,155	1,123	1,091	1,059	1,027	995	962	930	898	866	834	802
5%	1,251	1,223	1,195	1,167	1,139	1,112	1,084	1,056	1,028	1,000	973	945	917	889	862	834	806	778	750	723	695
6%	1,085	1,061	1,037	1,013	988	964	940	916	892	868	844	820	796	771	747	723	699	675	651	627	603
7%	942	921	900	880	859	838	817	796	775	754	733	712	691	670	649	628	607	586	565	544	524
8%	820	801	783	765	747	729	710	692	674	656	637	619	601	583	565	546	528	510	492	474	455
9%	714	698	682	666	650	634	619	603	587	571	555	539	523	508	492	476	460	444	428	412	397
10%	622	609	595	581	567	553	539	526	512	498	484	470	456	443	429	415	401	387	373	360	346
11%	543	531	519	507	495	483	471	459	447	435	423	411	398	386	374	362	350	338	326	314	302
12%	475	464	454	443	433	422	412	401	391	380	369	359	348	338	327	317	306	296	285	274	264
13%	416	406	397	388	379	370	360	351	342	333	323	314	305	296	286	277	268	259	249	240	231
14%	364	356	348	340	332	324	316	308	299	291	283	275	267	259	251	243	235	227	219	210	202
15%	320	312	305	298	291	284	277	270	263	256	249	241	234	227	220	213	206	199	192	185	178
16%	281	274	268	262	256	249	243	237	231	224	218	212	206	200	193	187	181	175	168	162	156
17%	247	241	236	230	225	219	214	208	203	197	192	186	181	175	170	164	159	154	148	143	137
18%	217	212	207	203	198	193	188	183	179	174	169	164	159	154	150	145	140	135	130	125	121
19%	191	187	183	179	174	170	166	162	157	153	149	145	140	136	132	128	123	119	115	111	106
20%	169	165	161	157	154	150	146	142	139	135	131	127	124	120	116	112	109	105	101	97	94

Fig. 5. Application of all Regulatory Policies

VI. CONCLUSION

It has been found that there are some regulatory policies that most significantly impact the viability of installing ESSs, since they allow a large increase in financial income to provide certain services. In this aspect, the highlight is in the interventions in the energy market for price arbitrage and in the services of support of the power generation to the system.

Finally, it was observed that the greater variability in the viability analysis of the ESSs is not always in the scenarios themselves, but rather in the sub-scenarios, due to the high sensitivity of the final response to the WACC value. For any scenario or sub-scenario evaluated, any investment for WACC above 9% per year was unfeasible. For taxation, although it influences the final outcome, its sensitivity to the response is less significant in relation to the WACC variation.

As a result, it is of great importance the regulation not only of the technical and economic aspects that can directly influence the sector, but also of aspects whose interference is not direct, which should appear in the metrics of its modeling, such as the WACC and tax rate.

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