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Article

Demand Response Program Implementation Methodology: A Colombian Study Case

Juan D. Molina[1,*], Luisa F. Buitrago[1], Sandra M. Téllez[2], Sandra Y. Giraldo[3], and Jaime A. Uribe[4]

[1] Colombia Inteligente, Medellín, Colombia.
[2] Facultad de ingeniería, Universidad Nacional de Colombia, Bogotá, Colombia.
[3] Facultad de ingeniería, Universidad de Medellín, Medellín, Colombia.
[4] XM, Medellín, Colombia.
[*] Correspondence: juandavid.molina@colombiainteligente.org

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Abstract: The industrialization and urbanization are responsible for Greenhouse Gas (GHG) emissions and could generate energy shortage problems. The application of Demand Response (DR) programs enables the user to be empowered towards a conscious consumption of energy, allowing the reduction or displacement of the demand for electrical energy, contributing to the sustainable development of the sector and the operational efficiency of the electrical system, among others. A reference framework for this type of program is detailed along with a literature survey applied to the Colombian case. The considerations on the design of a methodology to the implementation of the DR pilot, considering if the pilot is in an interconnected system zone or non-interconnected system zone and the application of the design methodology in the modeling of three DR pilots in Colombia is presented. For the modeling of the pilots, the characteristics of the area and the base consumption of the users are considered, and the characteristics and assumptions of the pilot are also defined. Furthermore, the DR pilot in each zone considering four types of users is detailed. The results show the potential for energy reduction and displacement in different time bands for each zone, which allows determining the assessment of the benefits from a technical, financial, and environmental point of view, and the costs of each pilot in monetary terms, it not to compare the pilots with each other, but to illustrate the values that must be taken into account in those analyses. The sensitivity analysis of each pilot was also carried out, considering the variation of the benefit/cost relationship with the energy rate in peak hours vs. off-peak hours and the base energy rate in the area. The sensitivity analysis shows that, when varying the level of energy demand response and the number of pilot participants, the values are presented when the benefit/cost ratio is greater than 1. In addition, the paper provides specific recommendations related to the design of a methodology and the implementation in a pilot DR using simulation.

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1. Introduction

The global electricity demand is gradually increasing over time, which implies an increase in greenhouse gas (GHG) emissions and their related effects on the environment. Factors such as the daily and seasonal variability of demand and the availability of primary energy resources represent new challenges for energy security [1]. The challenging issue is therefore to continue the economic growth while ensuring efficient energy consumption in a context of environmental responsibility. One of the strategies developed to support the previously stated objectives is efficient demand management, which includes different aspects to achieve the active participation of energy users through DR programs [2, 3].

The application of DR programs aims to empower users to be aware of their consumption and contribute to the reduction or displacement of electricity demand, bringing benefits to themselves and the sustainable and resilient development of the sector [4]. It highlights the increase in the operational efficiency of the electricity system, the optimization of investments in electricity infrastructure for the provision of the service, and the integration of technology by the user.

Each country or region has particular characteristics that need to be considered in DR programs [5]. Colombia has an annual per capita consumption of 1,312 kWh/inhabitant, a value that can be considered low when compared to the OECD value of 8,009 kWh/inhabitant [6]. The Colombian electricity sector has implemented DR programs that have demonstrated the ability of users to participate in the system. For example, the Apagar-Paga program achieved savings of 500 GWh and 170 MW in one month [7]; the mechanisms Voluntary Disconnectable Demand (DDV) and Demand Response in critical conditions registered availabilities of more than 171 MW and 76 MW, respectively. In addition, studies show a DR potential of up to 2,500 GWh in 2030, as well as an estimated mitigation potential of up to 2 MtCO2 for non-critical system conditions [8]. Therefore, mechanisms and programs are required to achieve this potential.

The diversity of criteria, requirements, and information needed to design a DR program is wide and depends on the local context [9]. It is necessary to consider, from the design stage of the pilot, aspects related to the analysis and evaluation of the DR program and communication strategies with the client, among others. Given the limited experience in Colombia in the design and implementation of DR programs, it is necessary to create a methodology that facilitates the supplying companies in going through all the associated processes and that allows the empowerment of the client guaranteeing the achievement of results. This paper presents the design and development of a methodology for the implementation of DR programs and its application to the Colombian case.

The objective of this paper is to present the design of a methodology for the implementation of DR programs and develop the simulation of a pilot to its application to the Colombian case. Three types of DR pilots are considered: two for the zones located in the National Interconnected System (NIS) and one for those located in the Non-Interconnected Zones (NIZ). In each pilot, the characteristics of the area and the base consumption of the users are considered, and the characteristics and assumptions of the pilot are also defined.

2. REFERENCE FRAMEWORK

This section presents the fundamental concepts related to DR, such as its definition, the stages and components of a DR program, and then the aspects for the empowerment of the user participating in this type of programs. Finally, a state of art of this topic in the Colombian context is presented.

2.1. Fundamental concepts

DR is a mechanism used to manage the consumption of energy demand through actions that allow the reduction or displacement of the same. This is achieved by shifting energy consumption from peak periods, where consumption is higher, to off-peak periods, where consumption is lower, motivated by the increase in the price of energy at times of high demand and thus optimizing the use of electricity infrastructure [10]. However, encouraging active demand-side participation depends on economic incentives offered by participants' contributions or penalties for non-compliance with commitments.

A DR program can be defined as a set of criteria and requirements or attributes to plan, incentivize, activate, measure, verify and report the response of an individual or aggregated electricity demand in the technical-economic and environmental operation processes of the electricity system [11]. It is essential to know the consumption patterns of users; these vary according to the type of user, the region, and the type of activity they carry out. The United State Department of Energy (DOE) proposes two types of mechanisms to incentivize changes in consumption patterns: price-based programs and incentive-based programs [12]. To address all aspects associated with a DR program, the stages and components shown in Figure 1 are outlined.

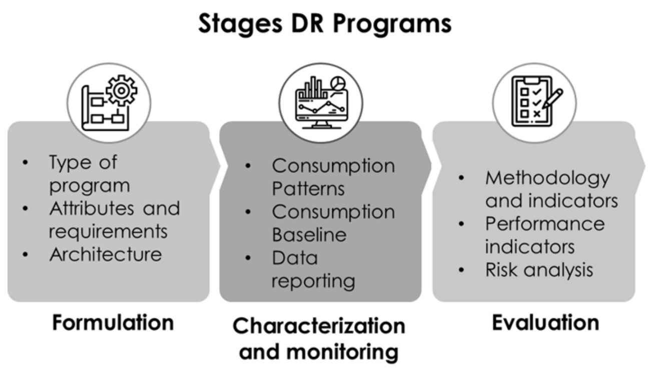

Figure 1. Stages and components of a DR program.

In the formulation stage, the type of program is identified, either incentive-based or price-based. For the Colombian case, the Intraday Tariffs, Load Management, and Market Demand programs are established [13]. For each one, the objectives and goals to be achieved with its implementation are defined, as well as the actions that allow promoting the program and its limitations. The attributes of the program are established, which depend on the type of market, available resources, the type of incentive received for effective participation, the period in which it is executed, among others. In addition, the technological architecture and standards of the DR program associated with the use of advanced measurement technologies, communication systems, and real-time management are defined.

For the characterization and monitoring of users participating in DR programs, it is necessary to know and standardize their energy consumption behavior, since this is one of the most important inputs for the electricity consumption baseline (CBL) [14].

To determine it, it is necessary to combine a variety of mathematical and statistical methodologies. The CBL must be calculated accurately to avoid bias since it will be used to compare the consumption pattern if the event had not materialized with the consumption pattern when the event does occur. Criteria of quality, accuracy, completeness, simplicity, and alignment should be included. An important component is communication with the user, which should include the awareness and data reporting stage of the program operation.

In the final evaluation stage, a methodology for monitoring the DR programs is established to quantify the economic, energy, and environmental impacts of their implementation. The comparison of Ex-ante and Ex-post conditions makes allows analyzing the programs results and establishing the necessary improvements and corrections. Technical indicators refer to energy demand, such as average energy reduction levels or per event, in peak or off-peak hours, per user and, per economic sector, among others. Economic indicators refer to the increase or reduction of money for all those involved in the system. Environmental indicators are intended to reflect the state of the environment as a result of the application of DR programs, specifically to evaluate greenhouse gas (GHG) emissions and other parameters. Social indicators refer to users and are defined in terms of those who participate in DR programs.

Additionally, aspects such as the difficulty of access to information, speculation in technology prices, and the levels of energy culture of the user should be considered as risks in the implementation of the program. A fundamental aspect of the success of DR programs is the empowerment, motivation, and loyalty of active users. For this, it is necessary to consider the aspects shown in Figure 2.

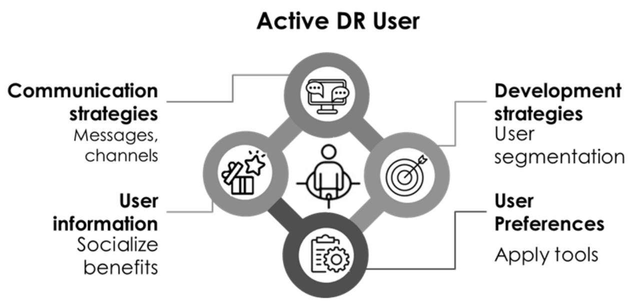

Figure 2. Aspects for empowering the active user of DR programs.

In each DR program, the reporting of data to the user is fundamental for his empowerment. Detailed information on consumption is one of the bases for promoting energy culture and obtaining responses from the user. Considering the segmentation of users according to different socio-cultural and demographic conditions is vital to increase the effectiveness of the programs and communication strategies needed to make users aware of the different DR programs and their operating principles: generating expectation campaigns, digital marketing, campaigns through leaders and experiential experiences. For DR programs to be successfully implemented, it is necessary to raise user awareness beforehand by informing them of the main aspects of the respective program. It is also essential to have different means of two-way communication between the end-user and the company offering the program. Furthermore, it is important to identify user preferences to learn about the different perceptions people have of the DR programs, the status of their implementation, and the main barriers; the development and application of research tools, such as surveys and targeted polls, are suggested.

2.2. State of the Art

To implement DR programs in the country, some public policy, the regulatory and normative background is taken into account: The guidelines on efficient energy management dictated by Law 1715 of 2014 [15], CREG resolutions associated with the mechanisms that have been enabled in the country (such as Voluntary Disconnectable Demand [16] and Apagar Paga [17, 18, 19], and other documents issued by the Ministry of Mines and Energy. It is necessary to highlight that a fundamental element is the tariff structure, which establishes the unit cost (UC) of providing the service, and allows the aggregation of cost components, using tariff formulas defined by the Commission or by market mechanisms.

Currently, the participation of demand in the Colombian context is limited to programs designed to support the operation of the electricity system under critical energy supply conditions, especially those associated with extreme weather phenomena such as El Niño. It is necessary to enable demand with participation tools in normal conditions of the electric system, taking into account the particularities of the Colombian electricity market.

3. DESIGN OF THE METHODOLOGY

The implementation of DR program pilots will allow to test the validity of the assumptions considered in the design of the programs, identify the components of successes and failures to intervene, test the effectiveness and relevance of the instruments, methodology, and protocols designed for the programs and identify the variables of interest and how to measure them conveniently. In this work, two types of DR pilots were considered: one for the zones located in the National Interconnected System (NIS) and the other for those located in the Non-Interconnected Zones (NIZ). This main differentiation is made taking into account that the electricity supply in each of these cases differs in the characteristics of the electricity system, costs, and environmental impacts, which influences the evaluation and monitoring methodology. For the design of the pilot, five stages are defined, together with their corresponding activities, as shown in Table 1. These stages must be executed sequentially, verifying compliance with each activity.

Table 1. RD PILOT DESIGN STAGES

Stage	Activities
Planning	Location selection
	Actors: Roles and responsibilities. Users
	Define promotion strategy
	DR Program: Attributes, incentives, and infrastructure.
	Valuation of the pilot
Pre-installation	Validation of participants
	Validation of DR program attributes
	Implementation of promotion strategy
Installation	AMI technology and telecommunications configuration
	Load control elements (optional)
	Follow-up of promotion strategy
Execution	Incentive application
	Consumption measurement
	Monitoring of promotion strategy
Evaluation	Determination of consumption changes
	Determination of performance indicators
	Evaluation of incentives and user response

In each phase, it is necessary to define the execution schedule, the responsibilities matrix, and the risk matrix. Each of the activities that make up the stages involves gathering and analyzing information and executing a systematic procedure. As an example of one of the activities, Figure 3 shows the flowchart for site selection for the NIS.

As a result of this analysis, the following is the design of the DR pilot in three zones: one located in a NIZ and two locations associated with the NIS; the particular conditions of each zone are different in demographics, climate, socioeconomic conditions, and productive activities. The pilot design aims to establish the order of magnitude of potential benefits and costs to estimate funding requirements.

For the three zones, the DR program considers that the level of demand response is given by a price signal or incentive that modifies the electricity consumption, displacement, and reduction. For the valuation of the DR pilot, an analysis of its potential benefits and estimated costs is carried out. Some of the considerations are:

- In the absence of tariff mechanisms, the valuation of benefits considers equivalent values that emulate an hourly/slot rate and a number of events that reflect a reduction or displacement at the hourly level.

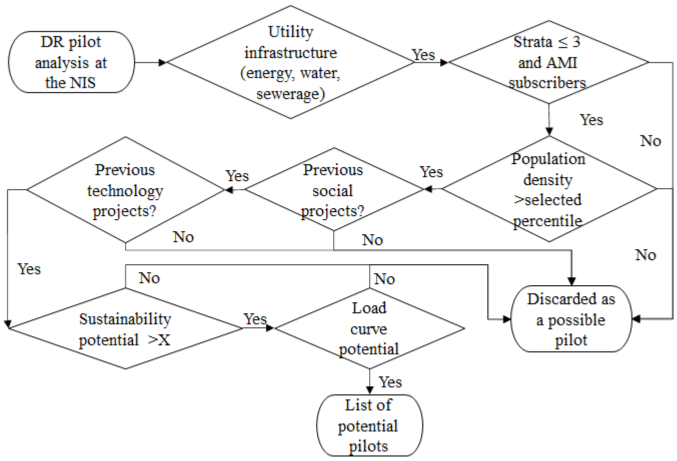

Figure 3. Analysis of the pilot location of the DR program in NIS

- The analysis of energy consumption is based on public information Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as "3.5-inch disk drive".
- Only those benefits that could be evaluated within the execution of a 6-month pilot will be considered.

4. STUDY CASE

For the modeling of the pilots, the characteristics of the area and the base consumption of the users are considered, and the characteristics and assumptions of the pilot are also defined. It is important to consider that the design could be made based on aggregate curves of available information and current price signals. However, it is important to highlight that participation in the DR programs requires individual action to achieve an efficient allocation of incentives; therefore, it is necessary to establish specific and hourly behaviors for each type of user.

Figure 4 shows 4 types of users, named after representative Colombian animals: The first one is the residential user, whose behavior is called the lazy bear, since its consumption varies once or twice a day; the second type of user is called the turtle, whose consumption is associated with daytime work activities; this type of user can be commercial or industrial. The third type of user is the manatee, whose consumption does not vary significantly during the day; the frog type user has a consumption without a defined pattern and is not related to the hours of the day; and finally, the opossum type user, whose consumption is mainly nocturnal.

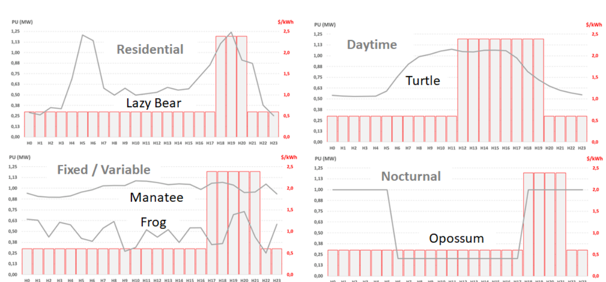

Figure 4. Main consumption profiles in Colombia.

The definition of a price signal or incentive should be aligned with consumption behavior and for each type of user, the range in which a price signal or incentive is required to achieve a change in consumption behavior or event should be established according to the type of application at which the DR program is aimed. According to the above, the following criteria are established to model the DR potential (displacement/reduction):

- Peak slots are assigned based on peak consumption hours and taking into account the peak of the national consumption profile.
- Sensitivities are required concerning the peak-slot-valley tariff ratio.
- Groupings of day types are related to associated consumption profiles; similar profile shapes allow the grouping of corresponding days.
- The delta DR considers aspects of the environment such as climate, rural or urban location, and the customer's main activity. These factors influence consumption flexibility.
- The ability to shift and reduce consumption varies in each time slot for each type of user.
- The customer's response to the tariff variation is not immediate and the gradualness of the change depends mainly on its main or productive activity.
- The potential for consumption variation is directly related to the level of power consumed in each band and its flexibility in each band.

For the simulation of the pilot, reference curves are obtained which are defined by the consumption level at the hourly level (blue line), the time slot (red/grey bars), and the demand response (green line, a positive value (+) means a reduction in consumption and a negative value (-) means an increase in consumption concerning the base case). Three types of days are considered, grouped by their similarities in consumption profiles: type 1 (T1: Monday to Friday), type 2 (T2: Saturdays), type 3 days (T3: Sundays, holidays, and special days). Figure 5 shows some examples of the results obtained.

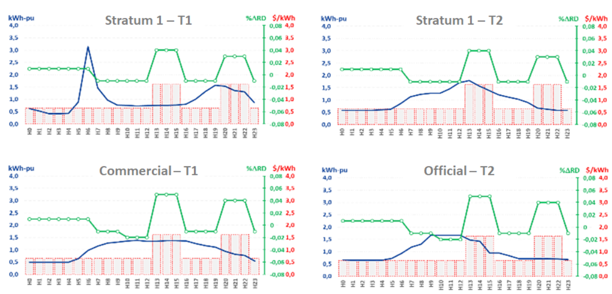

Figure 5. Relationships between consumption, tariff, and Delta DR.

For the valuation of the pilot, three categories of benefits are proposed: technical (Tec), economic (E-F), and environmental (Env). Table 2 includes the complete list, including the quantification of each benefit in their respective units and the monetization in thousands of COP for each of the 3 zones (Z) previously chosen. Z1 and Z2 correspond to two different locations, both located within the National Interconnected System and Z3 while Z3 is in the non-interconnected zone. It is important to emphasize that this comparison does not seek to show which pilot presents more benefits, but rather to illustrate to the reader the values that should be taken into account when performing this type of analysis.

Table 2. DR PILOT BENEFIT ANALYSIS

Type	Benefit [unit].	Benefit Quantification			Economic valuation (Thousands of COP)		
		Z1	Z2	Z3	Z1	Z2	Z3
Tec	Decrease in the duration of interruptions [min-year]	41	38	55	2,6	1,9	1,4
	Decrease in the number of interruptions [times/year]	1	3	1	2,6	1,9	1,4
	Decrease in consumption during peak hours [GWh]	99	65	12	98,8	55,4	10,9
	Decrease in energy losses [GWh]	11	7	1	523	350	40
E - F	Incentive payments -Reduction- [GWh]	159	95	14	1,5	951	144
	Incentive payments -Displacement- [GWh]	20	10	6	202	97	59
	Decrease in subsidies -Reduction and displacement- [GWh]	8	6	2	-7,1	11,9	18,9
	Bill savings -Expenses avoided- [GWh]	139	85	9	215,1	258,2	67,7
	Decrease in system operating costs [GWh]	139	85	9	24,5	15,7	3,9
Env	Mitigation of GHG emissions [CO2e]	53	33	6	344,5	212,3	79,3
	Decrease in fuel consumption [GWh]	139	85	9	815	502	50
	TOTAL				684,3	559,4	306,2

For the valuation of costs (Table 3), only those related to telecommunication equipment, data plan, and platform for access to information, human resources for managing the DR program, and the quantification of incentives designed for the pilot are considered; these costs will be assumed by the bidding company. For each cost, it is specified whether it is an Investment (I) or Administration, Operation, and Maintenance (AOM) cost. The user of the DR program may incur optional costs, such as the adaptation and installation of technology within its property; these costs are beyond the scope of this work.

Table 3. DR PILOT COST VALUATION

Item	Pilot Value - $ Millions COP zone 1		Pilot Value - $ Millions COP zone 2		Pilot Value - $Millions COP zone 3	
	I	AOM	I	AOM	I	AOM
Telecommunication equipment and data plan	-	192	-	150	-	90
Information platform - desktop/mobile -	-	16	-	13	-	12
DR Program Management - DR Team	-	18	-	28	-	28
Communication and training plan	173	-	142	-	72	-
Monitoring plan	144	-	125	-	67	-
Incentives	-	11	-	6	-	1
Subtotal	317	236	267	196	138	131
DR program cost		553		463		269

The consolidated results of benefits and costs for the three DR pilot zones are shown in Table 4.

Table 4. CONSOLIDATED RESULTS PROFIT/COST OF DR PILOTS

	Thousands COP	
Pilot	Benefits	Costs
Zone 1	$ 684.358	$ 553.127
Zone 2	$ 559.392	$ 462.766
Zone 3	$ 306.213	$ 269.023

The design of the pilot raises some questions such as: ¿What will be the level of demand response (demand elasticity), ¿what will be the efficient number of slots and their duration? ¿what is the efficient value of the slots? and is there certainty about the realization of benefits and costs? To answer these questions, it is necessary to evaluate the sensitivity of the pilot: an analysis was carried out to establish how benefits and costs vary when the value of the peak hour tariff is modified vs. the relationship between the off-peak tariff and the base energy tariff in the area. The sensitivity was also analyzed when the level of demand response (ΔDR) and the number of participants in the program was modified.

For the case of zone 1, as shown in Figure 6, the sensitivity analysis of the pilot shows that the base case (red dot) is obtained for 70% of the off-peak hourly cost ratio concerning the base tariff (y-axis) and 2.5 times the peak value concerning the off-peak value (x-axis). The green zone indicates that, from the pilot valuation point of view, the user would benefit from participating in the DR pilot to the established ranges and values (the white zone would be the limit of indifference between participating in the DR program or not).

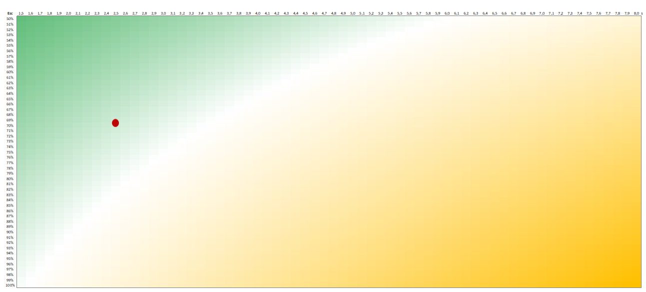

Figure 6. Graphic analysis of tariff variation sensitivity (Zone 1).

In general, the sensitivities consider that the value of the off-peak band (to shift consumption to this band) ranges between 50% and 100% of a user's base tariff. On the other hand, for the peak value, reference values were considered for the cost of rationing and the different demand steps (1.5%, 5%, and 10%). Therefore, considering that step 3 represents an impact on demand of 10% (higher than the assumption considered for the DR contribution), the sensitivity of the peak value/value ranges from 1.5 to 8, where the latter point represents the approximate ratio between the rationing cost of step 3 published by UPME [20] and the base tariff of the zone.

Similarly, the sensitivity analysis shows that, when varying the level of energy demand response and the number of pilot participants, the values are presented when the benefit/cost ratio (B/C) is greater than 1 (green cells). The first column represents the percentage by which the demand response may vary and, the first row represents the percentage by which the number of users participating in the pilot may vary. Figure 7 shows the results for zone 1.

5. RECOMMENDATIONS

- During the execution of the pilot, it is important to evaluate aspects such as the willingness to change (ΔDR per band) during the pilot and validation of the price-demand elasticity, changes in daily

B/C	50%	80%	90%	95%	100%	105%	110%	120%	150%
50%	0,36	0,57	0,64	0,67	0,71	0,74	0,78	0,85	1,05
55%	0,39	0,61	0,69	0,73	0,76	0,80	0,84	0,91	1,13
60%	0,42	0,66	0,74	0,78	0,82	0,86	0,90	0,97	1,21
65%	0,44	0,70	0,78	0,83	0,87	0,91	0,95	1,04	1,29
70%	0,47	0,74	0,83	0,88	0,92	0,97	1,01	1,10	1,37
75%	0,50	0,78	0,88	0,93	0,97	1,02	1,07	1,16	1,45
80%	0,52	0,83	0,93	0,98	1,03	1,08	1,13	1,23	1,52
85%	0,55	0,87	0,97	1,03	1,08	1,13	1,19	1,29	1,60
90%	0,58	0,91	1,02	1,08	1,13	1,19	1,24	1,35	1,68
95%	0,60	0,95	1,07	1,13	1,18	1,24	1,30	1,41	1,76
100%	0,63	1,00	1,12	1,18	1,24	1,30	1,36	1,48	1,83
105%	0,66	1,04	1,16	1,23	1,29	1,35	1,41	1,54	1,91
110%	0,68	1,08	1,21	1,28	1,34	1,41	1,47	1,60	1,99
115%	0,71	1,12	1,26	1,33	1,39	1,46	1,53	1,66	2,06
120%	0,74	1,16	1,30	1,38	1,45	1,52	1,59	1,72	2,14
125%	0,76	1,21	1,35	1,42	1,50	1,57	1,64	1,79	2,21
130%	0,79	1,25	1,40	1,47	1,55	1,62	1,70	1,85	2,29
135%	0,82	1,29	1,45	1,52	1,60	1,68	1,76	1,91	2,37
140%	0,84	1,33	1,49	1,57	1,65	1,73	1,81	1,97	2,44
145%	0,87	1,37	1,54	1,62	1,70	1,79	1,87	2,03	2,52
150%	0,90	1,41	1,58	1,67	1,75	1,84	1,92	2,09	2,59

Figure 7. Sensitivity analysis of tariff variation (Zone 1).

consumption, the impact of price variations and tariff components, and participation in the pilot considering the impact between the base tariff and the hourly tariff.

- The main recommendations are made to deepen the mechanisms that could enhance and encourage the active participation of users in DR programs, taking into account the identification and segmentation, the type and quality of the information transmitted, the knowledge of preferences related to DR programs, and the promotion strategies that should be applied for the development of DR pilots. Communication strategies should be designed in such a way as to allow users to learn about the different DR programs and the operating schemes of these mechanisms.

- The promotion strategies implemented should allow for continuous interaction between the users and the company offering the program, and the so-called DR program notifications should be delivered on time.

- The selection of the strategy must be based on the characterization and segmentation of the users so that the messages, channels, and other elements of the strategy are suitable for each type of user.

- To characterize and monitor user behavior, the consumption baseline must be constructed taking into account the following criteria: quality, accuracy, completeness, simplicity, and alignment.

- The different stakeholders involved in the development of the pilot must be defined. It is necessary to highlight that these stakeholders can be governmental entities, companies of the sector, and the users of the energy service. The results of a simulation to the DR pilot show the potential for energy reduction and displacement in different time bands for each zone, which allows determining the assessment of the benefits from a point of view technical, financial, and environmental, and the cost of each pilot in monetary terms, it not to compare the pilots with each other, but to illustrate the value that must be take into account in that analysis.

- The sensitivities consider that the value of the off-peak band (to shift consumption to this band) ranges between 50 % and 100 % of a user's current tariff., and the sensitivity of the peak value/value range from 1.5 to 8. Similarly, the sensitivity analysis shows that, when varying the level of energy demand response and the number of pilot participants, the values are presented when the benefit/cost ratio is greater than 1.

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