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Market Mechanism to Assess Demand Response Programs during the Energy Transition in the Wholesale Electricity Market of the Dominican Republic

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ABSTRACT

Modeling techniques have shown that fossil generation can be complemented with renewables and resources capable of providing flexibility in the operation of the system, according to the rules of the electricity market. In order to involve flexible demand, a market scheme is proposed that encourages it and that its adequacy allows the conditions to increase renewable participation to contribute to the reduction of CO_2 emissions. The model tested indicates that by shifting 10.49% from the peak to the off-peak block of the curve, an additional 5% increase in renewable penetration is obtained, and a reduction in the cost of supply of 8.4%. Considering a variation of emissions cost from 0 to 10 $/Ton of CO_2, the cost of supply increases to 16.03%, with a renewable participation of 12%. And the cost of supply improves by 7.27% when the penetration of renewables reaches 17%. According to the verified results, this tool is useful to evaluate the system operation programs and their effects on the market, contributing to decision-making for selecting the best operational scenarios, especially when subsidy and quality service problems are underlying.

Keywords: CO_2 emissions, demand response, elasticity of substitution, energy policy, renewable energy, wholesale electricity market

NONMENCLATURE

Abbreviations	
DR	Demand Response
DRP	Demand Response Program
DC	Direct Current
CES	Coefficient of Elasticity of Substitution
CO_2	Carbon Dioxide
IPCC	Intergovernmental Panel on Climate Change

1. INTRODUCTION

Identifying consumers participating in demand response programs (DRP) and determining their performance are key to assessing the flexibility of the load that best suits these programs. The demand response (DR) has the objective of implementing actions to influence users' electricity consumption profiles. According to [1], non-generation resource is viewed as a non-conventional source of energy and has been used to diversify power market services, like stability, flexibility, and reliability of the energy supply. DR and energy storage are non-generation techniques and programs developed to support variable renewable energy integration and manage the grid more efficiently [2]. The integration of the demand side increases the flexibility of the electrical system. The fundamental goal is to control the demand and move it in the time axis according to generation availability.

In DRP application, some models utilize the concept of price-elasticity, motivating an effect of the linearizing demand curve at a specific operating point instead of considering the entire demand, creating a discontinuity

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in the decision-making process [3]. Unlike demand response models based on price-elasticity, a model based on constant elasticity of substitution means a continuous decision-making process, which allows for greater flexibility. In this paper, the displacement of demand is determined based on the criterion of the elasticity of substitution, weighing its effect on the generation dispatch, especially of renewables.

The main contributions of this paper are the following: (i) Shifting of consumers' load profile based on the concept of elasticity of substitution by the system operator, in order to ensure few deviations in the contemplated electricity budget while creating conditions for increasing the availability of variable renewable generation; (ii) Tool simulation with performance indicators for decision-making, focused on reducing de cost of generation supply and mitigating environmental pollution caused by carbon dioxide (CO_2) emissions.

The remaining sections of the manuscript are organized as follows. Section 2 shows the problem statement of a market-based approach. Section 3 describes the proposed methodoly for a study case. Section 4 presents results and discussion of the methodology applied in the wholesale electricity market of the Dominican Republic. Conclusions and future work are presented in Section 5.

2. PROBLEM STATEMENT

Fig. 1 is a problem tree that summarizes the factors involved in poor service quality and permanent subsidies in the electricity sector in the Dominican Republic. It is necessary to verify the behavior of fuel prices, the level of integration of distributed generation and renewable energies, network congestion and the planning of its expansion, the technical tariff, social and environmental policies, operational flexibility services, such as demand response, and storage to address these problems.

To analyze the impact that the mechanisms derived from applying an energy transition plan may have, as required by the Dominican Republic, according to what was expressed by [14], in relation to the goal of reducing greenhouse gas emissions by 25% by 2030, compared to 2010, and increase the share of renewables by 25% by 2025, it is convenient to explore optimal and innovative alternatives that are not capital intensive, and that effectively contribute in a complementary way to the process, as evidenced by some markets that have implemented demand response programs.

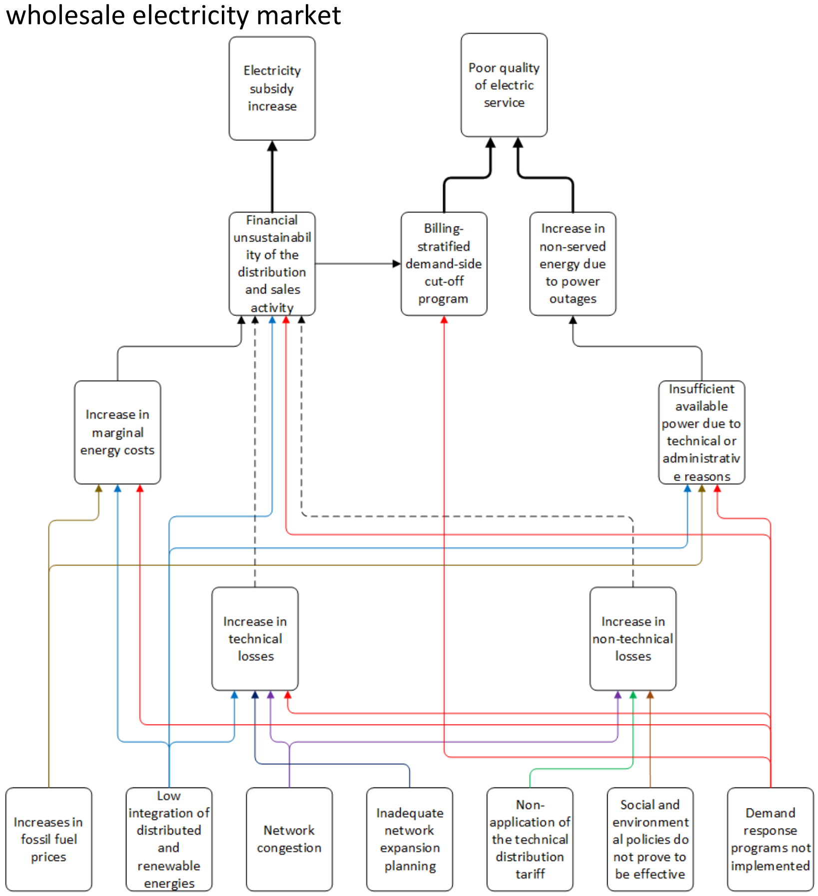

Fig. 1. Problems tree in the wholesale electricity market of the Dominican Republic

2.1 Objective

Develop an operation methodology for decision-making in energy policies applied to the wholesale electricity market, which considers demand response programs, based on consumer segmentation characteristics, utility functions in the substitution elasticity coefficients demand, and high penetration of non-conventional renewable energy, to contribute to sustainable development in the Dominican Republic.

3. METHODOLOGY

The proposed methodology assesses the application of DRP based on the load shifting strategy, from one hourly block to another, to minimize generation supply costs and contribute to the reduction of emissions of CO_2. The analysis considers a representative electrical system in a liberalized electricity market, simulated an optimal direct current (DC) power flow, without ohmic losses. Fig. 2 describes the sequence of activities that make up the methodology. It is based on the following criteria: prospecting of variable renewable energy, segmentation of consumption profiles from the elasticity of substitution, DRP based on incentives, and determining supply costs, considering economic and environmental perspectives.

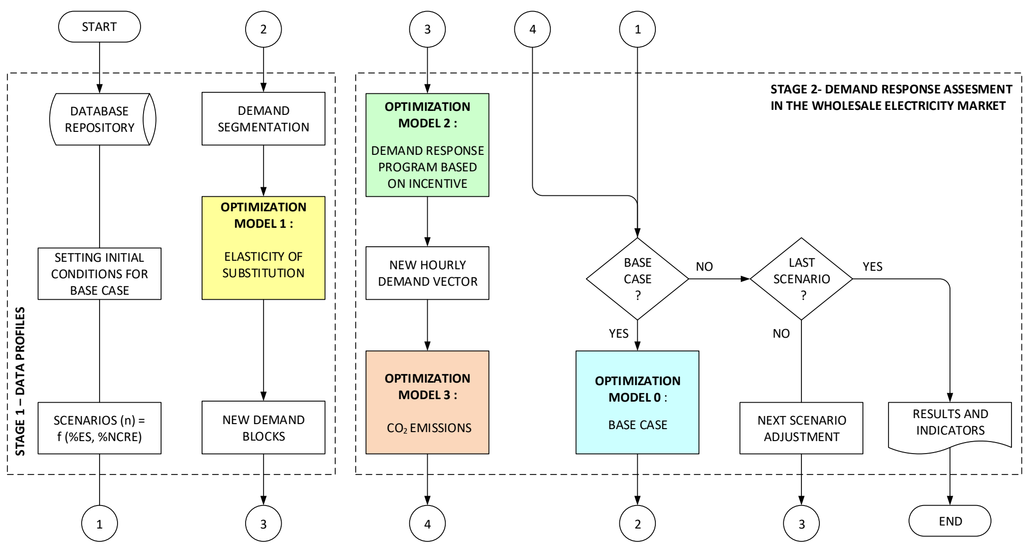

Fig. 2. Methodology of flexible demand participation in the wholesale electric market

Model 0 performs an economic dispatch that incorporates generation and network constraints. For comparative purposes, model 0 represents the base case, against which the different decision variables will be verified.

Model 1 is responsible for applying the load shifting strategy as the first stage of DR. In this model, the theoretical principle that supports demand displacement in the daily load curve obeys the elasticity of substitution for agents of the wholesale electricity market. The distribution of hourly demand is a functionality of model 2. In this second part of the DR process, an incentive scheme is defined to explore different demand schedules.

The quantification of the incentive to be recognized for the DRP participants' contribution is a component in determining the benefits that may accrue, considering that variations will influence the electricity billing process in electricity load and the market's marginal cost. To determine the benefits for all consumers who participate in DRP, participants, and non-participants, we proceed to verify the increase or reduction effect that occurs in the marginal costs resulting from the generation dispatch and in adjusted quantities of demand that allow the users' elasticities, for each hour, day and bus, included in the operation.

Finally, model 3 is coded from model 0, with the inclusion of the cost of CO_2 emissions and an approach to the conditions required for their reduction, according to the Intergovernmental Panel on Climate Change (IPCC) level 1 methodology. Economic and environmental indicators evaluate the behavior of the DRP, and the incentives required to motivate the participation of the demand.

The following Key Performance Indicators (KPI) are referred by [4] and used in the context of this evaluation scheme to show the applicability of DRP: Percentage variations in electricity load during peak hour block, Percentage variations in electricity load during off-peak hour block, Percentage ratio of non-served power respect to baseline consumption. Additionally, net profit for participants and non-participants in DRP is calculated.

3.1 Material and methods

The optimization procedure decomposes the problem into stages, linking models through recursive calculations. To meet this objective, mathematical programming in models 0 and 3 minimizes a MIP function using the CPLEX solver; and models 1 and 2 minimize an NLP function using CONOPT solver. The algorithm has been developed in GAMS code and tested with the following computational resources: Intel(R) Core (TM) i7-10510U CPU @ 1.80GHz 2.30 GHz, RAM 16.0 GB.

3.2 Modeling considerations

This section is structured based on publications dealing with the concepts of economic dispatch, as developed by [5], treatment of renewable generation and demand response according to [3, 6-8], coefficient of elasticity of substitution (CES) by [9] and CO_2 emission control by [10]. The description of the specifications contemplated in each stage are shown in Table 1.

This proposal has been tested programming the operation rules of the Wholesale Electricity Market of the Dominican Republic. Instead of using the Interconnected National Electricity System, the simulations are scaled using a modified IEEE standardized network of 14 buses.

For purposes of comparison with this paper, table 2 summarizes the contributions and key concepts underlying the energy management model proposals of research that consider the common element of the constant of elasticity of substitution, plus an operational concept, focused on one of the following criteria: load-shifting profile, energy technology change, variable renewable energy, and CO_2 emissions.

Table 1. Specifications and stages of the development model.

Stage	Concept description	Model 0	Model 1	Model 2	Model 3
Input	Data	Start-up cost, shutdown cost, variable production cost, value of loss load, water value, demand, spinning reserve, technical characteristics of generation, and network	Hourly demand and demand grouped by blocks, participants in DRP, parameters in CES function, marginal costs	Hourly demand and demand grouped by blocks, technical characteristics of demand, scenarios of demand probabilities	includes data from models 0 and 2, parameters for CO_2 emission control
Process	Decision variables	Energy generation, demand pumping, non-served energy	Residuals from the CES function	Energy demand adjusted by DRP, an incentive for participants in DRP	Energy generation, demand pumping, non-served energy, emissions of CO_2
	Objective function	Minimizing operation cost	Minimizing residuals from the approximate CES function	Maximizing incentive scheme	Minimizing operating cost, including emissions of CO_2
Output	Main results	Operating cost, power and reserve outputs of each generator, marginal costs	New demand blocks	New hourly demand, an incentive for participants in DRP	Operating cost, power and reserve outputs of each generator, marginal costs, CO_2 emissions, profit, and KPIs to evaluate DRP

Table 2. Summary of contributions and common key concepts of energy management proposals

Reference	Contributions	Recommendations	Highlighted concepts for comparative purposes				
			CES function	Load-shifting profile	Energy technology change	Variable renewable energy	CO_2 Emissions
[11]	Required investment in renewables and storage to decide on the expansion of the electric power system.	Incorporate operating and maintenance costs into the model.	x			x	
[12]	Analysis of the response of consumers with different incomes to changes in carbon allowance prices, for the long and short term.	Include transactional costs in the model, and the possibilities of participating in emissions market activities.	x				x
[13]	Develops methodology to determine technological change from capital, labor, and energy.	Consider elements to mitigate environmental damage and inefficiencies in the resulting energy-intensive sectors.	x		x		
[14]	Management of industrial loads from a demand response program based on Real Time Price, considering adaptability and adjustability criteria.	Due to the nature of the adjustments in the industrial load, it is necessary to evaluate the stability and quality effects on the electric power system.	x	x			
[15]	Describes the main aspects of econometric specification of the CES function for capital, labor, and energy inputs.	Conduct an applied case study based on the recommendations made.	x		x		

4. RESULTS AND DISCUSSION

Regarding the base case, the scenarios with the same limit of renewables' participation do not present a significant variation in the objective function, since the reductions are less than 0.4%. However, the effect of incorporating CO_2 constraints motivates changes in demand response. The simulation shows increments between 15.8 and 16.2%, when the price is \$10 per each ton of CO_2.

In each scenario of demand response, comparisons are made with the objective function in the base case, for initial penetration of variable renewable energy of 12%, like the maximum admissible in the base case and another of 17%, corresponding to the maximum allowed with the demand response program applied, verifying that the increase in renewables reduces the operating cost of the generation dispatch. If the cost of CO_2 emission is reduced to 0, renewables may increase by 5%. This reduction translates into the cost of supply by -8.4%, compared to the base case.

It is also observed that the incentive has allowed compensating all the participants in the DRP favorably. Another aspect to consider is the relative variation in load produced by elasticity of substitution, from 0.1% to 10.49% in the peak and shoulder blocks to the valley block.

In general, it is verified that the occurrence of the coincident maximum hourly demand for the weekly schedule changes from one demand block to another. In the base case, the maximum demand is recorded for period 131, at the 11th hour of the sixth day. After applying the load shift, the new period is 125, corresponding to the 5th hour of the sixth day. It may be noted that the maximum demand in the base case corresponds to a shoulder hour. Results show a reduction in the non-served power of 19.1% when the penetration level of renewable energies is increased by 5%.

This methodology's application reveals limitations when demand blocks saturate the CES function's sensitivity, since the effect of load shifting is minimal or does not occur, as verified in the peak-to-valley iterations of the case study, where variations of less than 5% of the base demand are verified, despite having limits that allow it. About the incentive scheme, the prudence of establishing the upper limit that defines its variability during the optimization process should be weighed, considering that high incentives can distort the nature of the regulatory mechanism and low values may not be attractive to DRP participants.

With this tool, the market operator in Dominican Republic can explore scenarios to reorder demand in the load curve and increase the penetration of renewables, contributing to the reduction of supply costs, the control of CO_2 emissions, and the containment of operating costs of distributors, highly impacted by existing energy losses. Additionally, demand incentives conditions are created, which improve the quality of service to end users, allowing the regulatory authority to reduce the conditions of staggered rationing, applied according to the payment indexes reached by stratified circuits.

According to the favorable evolution of the users' payment rates, the distribution companies modify the hours of service cut-off, according to the classification of the circuits, with a progressive tendency towards a permanent 24 hours a day service. Of course, this apparent solution of the cash flow of the distribution companies does not solve the problem, but transfers it to the end user, since the user must look for other options to guarantee the continuity of the service when it is not available in the distribution networks, motivating the permanence of the original causes that provoke the subsidy and the poor quality of the service.

5. CONCLUSIONS

This paper presents a market approach designed to solve the integration of a demand response program in the wholesale electricity market. The main findings can be outlined as follows:

(1) This proposal demonstrates that strategic demand shifts can be made to increase the dispatch of renewable power, considering security criteria, generation constraints, including the availability of the renewable resource, and the operational constraints of the transmission grid. For the case study, it was possible to increase the penetration of renewables by 5%, for a demand shift of less than 11% in the peak hour block of the load curve.

(2) In all scenarios, the cost of supply determined from the objective function does not present variations of more than 10%, due to the budget restriction imposed in the elasticity of substitution model, creating favorable conditions for the system operator, by providing comparative economic dispatch options, which allow setting the focus on the performance of renewables and therefore, on the control of greenhouse gas emissions.

(3) It is possible to perform sensitivity analysis for decision making, based on the indicators that determine the percentages of load displacement, the ratio of unserved power and the benefits of demand, obtained from an incentive scheme and the natural behavior of the market.

In the context of the Dominican Republic, government policies justify the application of a subsidy in the case of the electricity sector, as a result of the losses of the distribution companies and due to the composition of the generation matrix, mostly concentrated in technologies that use fossil fuels; However, the prospect is the progressive elimination of subsidies, considering that this represents an inefficient economic signal from the perspective of rational use of resources, although this may generate controversy and debate with social sectors, considering that it has served as an instrument of economic policy, motivating claims as targeted assistance to the neediest families.

Therefore, this proposal for a market mechanism supported by demand response programs can be evaluated to provide viable alternatives for the operation of the system, capable of mitigating the quality and subsidy problems.

For the continuity of future research on this subject, stated limitations should be considered. Therefore, the methodology can include the forecast of variable renewable energies, the exploration of demand segmentation criteria and the treatment of losses in the transmission activity, to reduce deviations between planning and operation. Another aspect to be considered in the forthcoming research work is the treatment of the demand-side disutility function, considering that this is the main barrier for the demand side to exercise flexibility. If not properly examined, the assessment of the benefit of demand flexibility could be too optimistic.

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