

# Consumers Modelling and Clustering for the Use of Flexibility to Mitigate Network Congestion

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**Keywords:** FLEXIBILITY, HOUSEHOLDS, CONSUMERS, CLUSTERING, DEMAND RESPONSE

## Abstract

This paper offers an overview of the H2020 DOMINOES project that conceives the study of implementation of a platform to incentivize demand response (DR) and participation in local energy markets. A novel approach of categorizing consumers is tested, grouping consumers according to their frequency of response to the flexibility needs. This methodology will allow to have new insights into the flexibility activation process, with focus on the process of encourage and engaging repeated participation of different consumers with different characteristics, preferences and needs. With this new approach, the activation process is adaptive targeting consumers with specific response categorization in order to obtain the required response reliability to meet market requests or grid needs. In terms of the grid supervisors, the impact of such methodology will allow DSOs to adapt and fine tune strategies for consumer targeting and address the individual or aggregated consumers that have high response rates and/or are easily responsive to incentives or have common interests or are keen to be market and system participative. This paper presents the DOMINOES project advances in the study of new, adaptative and non-intrusive scenarios of consumers classification that induce consumer participation, and develop the flexibility market, without ignoring the DSO's market neutrality.

## 1 Introduction

Currently, the energy sector is facing a new multidisciplinary challenge: the successful implementation of the truly Smart Grid concept in the actual grid networks. With the liberalization of the energy market and the urging environment concerns, innovative business models and approaches must be designed to deal with the requirements needed to accommodate new players and technologies [1]. Incentivize energy efficiency is one of the main options. The paradigm between consumption and production is changing and instead of dynamically adjusting non-renewable resources to satisfy the load needs, Demand-Side Management strategies are introduced by flexibility means such as shifting, peak shaving or direct load control – Demand Response (DR) techniques [2]. Also, the potential behind distributed and renewable generation (DG) is promoted, benefiting the local community with cheaper resources such as solar and wind energy. Although, consequences in the congestion of the grid can be noticed soon increasing the significance of Local Flexibility Markets (LFM). Active consumers can play an essential role in the support of Distribution System Operators (DSO) with participation in DR programs. In this way, with the proper method, constraint violations and overloads are avoided, finding a reasonable solution to prevent congestion and providing balance economically and ecologically. [3] The household consumers, being a significant part of the global consumption, become an important part of the management of the future energy market and the uncertainty of their response to DR events must be prevented to achieve

functional LFM. Studies validate the influence of the amount of recompense in the flexibility given [4], [5]. The new business model must consider a fair and appealing reward for discomfort and incentivize continuous participation.

H2020 DOMINOES project conceives and implements a platform to incentivize DR and participation in local energy markets. Reward payment to consumers and their location relative to the impact they have on-grid congestion is analysed.

A novel approach of categorizing consumers is tested, grouping consumers according to their frequency of response to the flexibility needs. After each event, consumers responses are verified, and their categorization is updated. This allows having new insights into the flexibility activation process. In this way, the activation process is adaptive targeting consumers with specific response categorization to obtain the required response reliability to meet market requests or grid needs. The DSO will be able to fine-tune consumer targeting and address individual (or aggregated) consumers who have high response rates and/or are easily responsive to incentives and have common interests or are keen to be market and system participative.

## 2. Methodology

In the proposed methodology, for each DR event occurring in day  $D$  and period  $t$ , a DR Reliability Rate ( $RR_{c,ev}$ ) is assigned to each consumer  $c$ , according to the consumer's actual response. The RR calculation considers the consumer's general historic rate ( $HR_c$ ), the historic cut rate for the given period ( $CR_{c,t}$ ), and the reliability rate for the previous

demand response event (RR<sub>c,ev-1</sub>). The HR<sub>c</sub> is determined according to all the existing historic data for consumer c. The HR starts at 0 when there is no historic data and decreases and/or increases according to the consumer's response. CR<sub>c,t</sub> is determined by the consumer c historic actual response for period t; the CR will increase, stay the same, or decrease if the actual reduction for that period is higher, equal or lower than the requested reduction, respectively. Considering the first time that reliability rates are applied, Fig. 1 initial rates depend only on the prior data regarding each consumer's actual response to DR events.

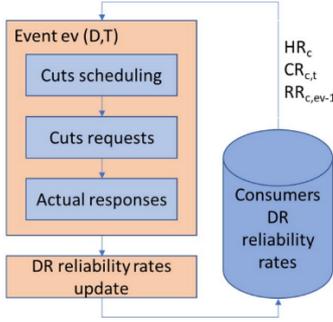


Fig. 1 Proposed Methodology.

Load shifts are scheduled according to an optimization process that uses the DR reliability rates. The objective is to minimize the operation costs and keep the non-supplied power value (NSP) null in all the situations. So, in a Scheduling phase, a linear optimization is performed. The input needs several parameters, and it is the responsibility of the managing entity to gather all the information from associated resources, for instance, regarding the maximum capacity of the DG units, the external suppliers and the reduction capacity of the consumers joining DR events, as well as the consumption tariffs associated with each resource is needed. Equation (1) introduces the objective function of the problem.

$$\text{Min OS} = \sum [P_{DG}(p, t) \cdot C_{DG}(p, t)] + \sum [P_{DR}(c, t) \cdot C_{IDR}(c, t)] + \sum [P_S(s, t) \cdot C_S(s, t)] + P_{NSP}(t) \cdot C_{NSP}(t) \quad (1)$$

The optimal scheduling is done for each period t and the different resources in the local community such as DG units (PDG), consumers belonging to DR programs (PDR) and a connection to the grid (PS). The production is managed to suppress the total amount of consumption and achieve the network balance, as presented in Equation (2). Several technical and operational constraints are also applied to the objective function as described in [4].

$$\sum [P^{initial}(c, t) - P_{IDR}(c, t)] = \sum [P_{DG}(p, t)] + \sum [P_S(s, t)] + P_{NSP}(t) \quad (2)$$

In the first stage, the scheduling only considers consumers with the best DR performance – RR superior to the denominated minimum. To define the quality of this performance, two different alternatives are considered: a) consumers with reliability rates above pre-defined thresholds;

b) consumers clusters with reliability rates above pre-defined thresholds. If the selected consumers are not sufficient to achieve the DR event target, all the remaining consumers are considered in a scheduling second stage – re-scheduling. Consumer clusters are generated according to the similarity of the reliability rates resorting to different clustering methods, namely k-means and c-means. A discussion between what regards consumer attributes and the obtained clusters will be presented in the Results Section.

### 3 Case Study

The dataset used to prove the viability of the proposed methodology is composed of 247 households and 25 photovoltaic resources (PV). To understand the willingness to participate in DR programs, a survey was presented to a universe of 48 elements: 94% from urban areas, 52% with ages between 30-40 years old; 83% had 2 – 4 person members living permanently at their household. Table 1 presents the survey results [6]. These consumers were associated indirectly to the dataset presented in Fig. 2 and the power consumption for each appliance selected as flexibility is applied as the capacity for DR events. Ten appliances were suggested to shift: domestic heater, electric cooker/oven, air-conditioning, dishwasher, washing machine, clothes dryer, desktop computer, coffee machine, electric iron and microwave oven [7].

Table 1 Survey Results for the willingness to shift appliances

	7-9AM	12-2PM	5-7PM	7-10PM
Certainly not	18%	16%	15%	22%
Not likely	18%	20%	17%	29%
Likely	15%	16%	25%	20%
Very Likely	17%	16%	19%	16%
Definitely yes	32%	31%	23%	13%

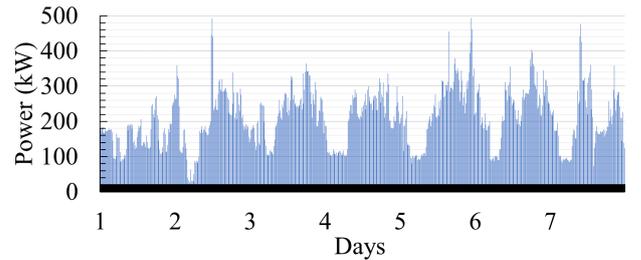


Fig. 2 Load Diagram of anonymized consumers, between January 1 and 7, 2019.

### 4 Results and Discussion

To test the proposed methodology in congestion situations and considering the outcomes from the survey, two DR events were triggered on Friday 4 and Sunday 6 from January 2019, between 3 PM and 4 PM in periods of 15 minutes. It is assumed a contingency where only 150kW can be distributed to the location of these consumers. So, the entity manager must balance the consumption and production resorting only on PV and consumers participating in DR programs, choosing the most reliable ones. In this way, three scenarios were created: no PV, half and full PV amount, respectively

Scenario 1,2 and 3. Fig. 3 demonstrates the global scheduling results from the mentioned scenarios for both DR event days: initial consumption, actual consumption, PV, NSP, requested DR and contingency limit.

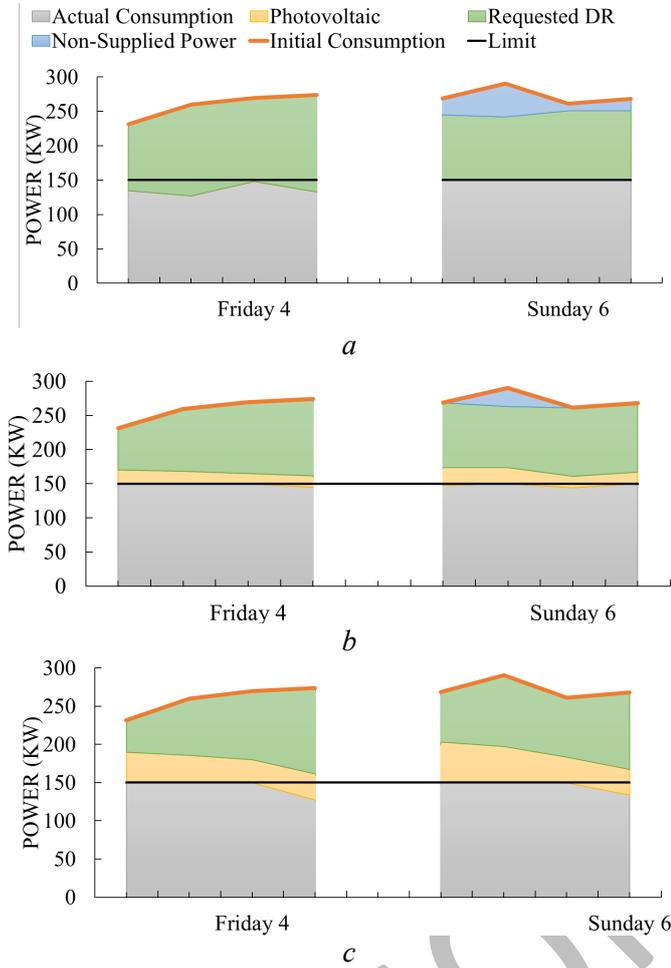


Fig. 3 Results from Scenario 1(a), Scenario 2 (b) and Scenario 3 (c)

The goal is to maintain the NSP value null. So, no DR target is defined, as in previous works, but the community manager must use this flexibility to reduce the chance of consumption not supplied mitigating the network congestion. Some cases may require a Re-scheduling phase since consumers with high-reliability rate are the ones selected for Scheduling and their reduction capacity may not be enough to successfully find balance. In these three scenarios, the consumers were chosen to participate individually and some of them were not willing to lose discomfort on the weekend so, the reduction capacity decreased.

The discussion will be made per day comparing scenarios. For Friday, in the first scenario, the generation value required from the external was underneath the threshold through periods, noticing an increase in requested reduction from DR. Regarding the actual reduction from participants, was higher than expected. In the second scenario, the number of re-scheduling decreased for most of the event periods, resulting in fewer consumers requested to participate in the DR event, so the external generation quota value is higher than the

previous, being equal to the contingency limit. The value of requested reduction decreased also, thanks to the introduction of PV, where all the amount was used. In the last scenario, the actual reduction was superior to the requested proving that selected consumers with RR higher react according. For Sunday, the conditions to deploy a DR event were worst – fewer consumers participating. The outcome from this result is noticed on NSP value since, although the efforts to keep this value null, was not possible until the scene where the full PV capacity was introduced. Moving to an individual perspective, five consumers were chosen to compare behaviours through both DR events perceiving the effects of RR. Fig.4 like the previous one, shows the scheduling results confronting consumer consumption, requested and actual reduction. Table 2, to complement this information, present also the RR for each selected consumer to appreciate how the proposed methodology penalizes or reward participation according to lower or higher responses.

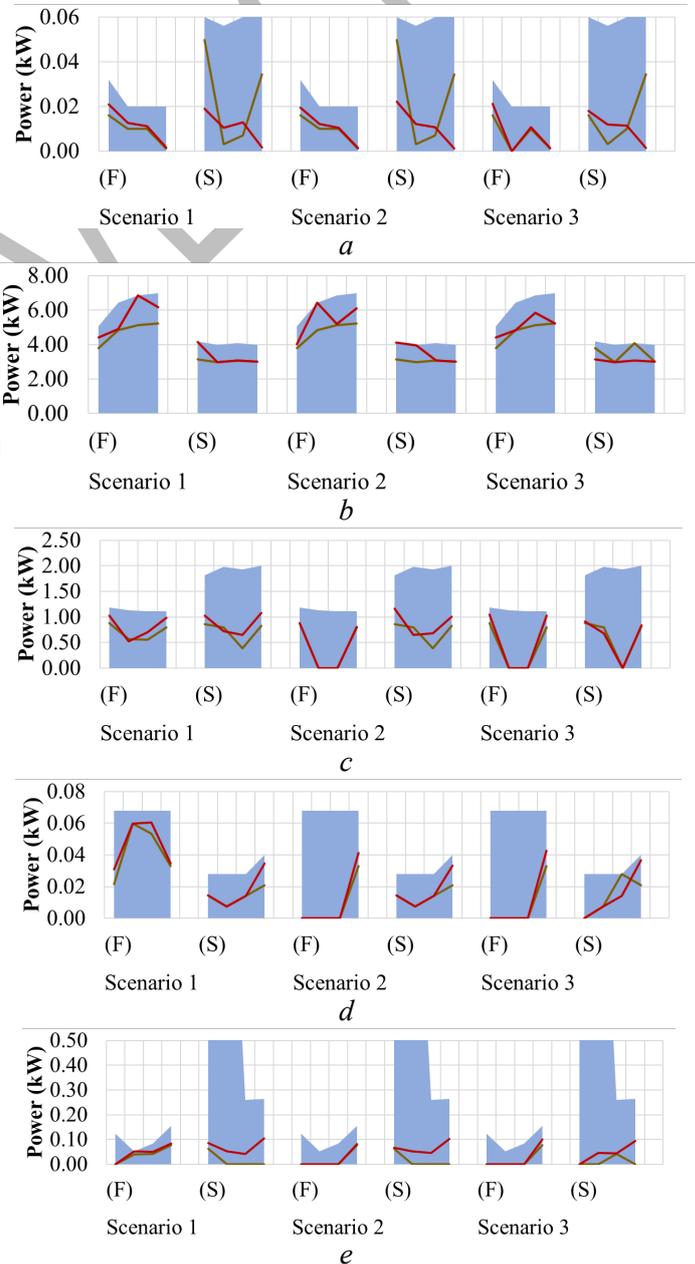


Fig. 4 Results from Consumer 1(a), Consumer 2 (b), Consumer 3 (c), Consumer 4 (d) and Consumer 5 (e) (F – Friday; S – Sunday)

Table 2 Reliability Rate per DR event for selected consumers (F – Friday; S – Sunday)

Consumer	HR		Scenarios					
			1		2		3	
	F	S	F	S	F	S	F	S
1	3	3	5	4	4	3	5	4
2	2	4	4	4	5	5	3	4
3	3	2	4	4	4	4	3	4
4	3	2	3	4	3	4	4	3
5	3	2	4	3	4	4	4	4

Consumer 5 (Fig. 4(e)), was the one with better performance since his actual responses to DR event was always higher or equal to the requested by the manager. In this way, with this result, was able to improve the RR. The remuneration to reward the consumers for their performance in DR events is an important way to incentivize continuous participation. Regarding this matter, and to assess the individual and aggregated selection of participants, two clustering methods were compared regarding final remuneration – k-means and c-means. Scenario 3 assumptions were considered, and the consumers were clustered according to RR and reduction capacity. The results were similar, being able to easily schedule the resources without resorting to more other consumers than the selected. The outcome indicates that more profit from the perspective of the entity manager can be obtained with c-means, meaning final remuneration values are lower.

## 5 Conclusion

H2020 DOMINOES project focuses on consumers to incentivize DR and participation in local energy markets. The proposed methodology designs and assigns a reliability rate to trustworthy consumers for their response in DR events. The idea is to provide the entity manager behind these active resources, not only DR programs participants, but also PV with information useful to mitigate network congestion situations. Three situations were simulated, and the viability of the method was proved to be able to balance the local community using flexibility means, dealing with the uncertainty associated.

## 6 Acknowledgements

This paper is the result of an integrative and collaborative partnership between the GECAD Research Group from the Polytechnic of Porto (ISEP/IPP) and EDP Distribuição – Energia S.A. developed within the Horizon 2020 Project DOMINOES (grant agreement No771066). The present work was done and funded in the scope of the following projects: UIDB/00760/2020, CEECIND/02887/2017, and SFRH/BD/144200/2019 supported by national funds through FCT. The consumers' data used in this study are 100% anonymized, being all of the content associated with confidential and sensitive content compliant with the

Regulation (EU) 2016/679 – General Data Protection Regulation – and other laws and regulations applicable to the electricity sector. Nevertheless, the anonymized data content associated with this study is subject of elimination until the end of the DOMINOES project, on 31st of March of 2021.

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