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SCHEMES FOR FLEXIBILITY PROVISION AMONG RESIDENTIAL CONSUMERS: VALUE PROPOSITIONS FOR AUTOMATED FLEXIBILITY

ABSTRACT

Demand response (DR) schemes enhance grid flexibility and enable the growing uptake of renewable energy sources. Traditionally, DR schemes are classified into implicit (price-based) and explicit (incentive-based) flexibility. Both types of DR can be implemented as either automated schemes or as manual mechanisms. Automated flexibility (AF) leverages smart devices to automatically and dynamically adjust energy consumption based on system needs, offering a seamless experience compared to traditional DR schemes. Despite these advantages, much of the literature and research to date has focused on consumer engagement with manual schemes, leaving a gap in understanding how automation can facilitate participation. This paper investigates consumer perceptions of AF, focusing on how automation mitigates consumer pains in energy use and management. An interpretive study involving nineteen consumers from Spain, Italy, and France reveals that consumers are more likely to engage in flexibility schemes when automation alleviates the burdens associated with manual adjustments, uncertainty, and loss of control. These findings suggest that AF could enhance consumer participation in DR schemes as it addresses key barriers. This study contributes to the energy sector by identifying value propositions that make DR more attractive and user-friendly for residential customers.

Keywords: Automated flexibility (AF), consumer participation, demand response (DR), PV systems (PVS), electric vehicles (EV), electrical heating and cooling.

Highlights:

- DR includes implicit and explicit approaches, both of which can be automated (AF) or manual.
- Most research has focused on manual schemes, leaving a gap in the study of AF.
- AF mitigates consumer pains related to manual adjustments, uncertainty, and loss of control.
- Consumers with PVS seek to optimise self-consumption rather than just maximise profits.
- AF in electrical heating/cooling reduces effort and increases efficiency.
- EV users value automation for reduced manual programming and cost predictability.
- Concerns over battery degradation remain a key barrier to EV user participation in AF.

1. INTRODUCTION

The increasing integration of renewable energy sources (RES) into power systems necessitates enhanced grid flexibility to accommodate the variability and unpredictability of wind and solar power [1]. Demand response (DR) has emerged as a vital tool for flexibility [2, 3]. DR schemes can be broadly categorised into implicit (price-based) and explicit (incentive-based) flexibility [4, 5]. In implicit flexibility schemes, consumers are expected to adjust their energy consumption in response to changing prices, shifting their usage away from peak times. In contrast, explicit flexibility schemes incentivise consumers to adjust their energy consumption according to system needs, which may involve consuming more or less energy at specific times [6]. Both approaches can be implemented in two ways: as automated schemes, where smart devices autonomously manage energy consumption without consumer intervention, or as response-to-signal schemes, where consumers manually react to system signals (price or incentives). Most of the existing research has focused on consumer participation in manual response-to-signal schemes, leaving a gap in the understanding of how automation can facilitate demand-side flexibility [6, 7]. This understanding is crucial since residential consumer engagement remains a challenge due to reluctance to change energy use behaviours and concerns over loss of autonomy [8].

This study addresses this gap by exploring consumer perceptions of automated flexibility. Automation enables smart devices, such as PV systems, thermostats and electric vehicle chargers, to dynamically adjust energy consumption based on system needs, providing a seamless experience and reducing the cognitive burden on users [9–11]. This automation could enhance consumer engagement in flexibility schemes by eliminating barriers to enrolling in implicit and explicit flexibility, such as effort involved, difficulties in changing energy-related uncertainty in energy management, and perceived loss of control over consumption [6, 9, 12]. Moreover, it can offer consumers a wider range of benefits beyond the monetary and environmental gains previously associated with other forms of flexibility provision [13, 14]. Because it provides greater benefits with fewer drawbacks, AF could be a particularly attractive option for facilitating residential consumer engagement with DR.

2. A CHARACTERISATION OF FLEXIBILITY SCHEMES

Flexibility in demand response (DR) schemes plays a crucial role in enhancing grid stability and facilitating the integration of renewable energy sources [1]. DR schemes are broadly classified into two main types: implicit flexibility and explicit flexibility [3]. These types can be further differentiated based on their implementation as automated or manual schemes. This characterisation reflects the diversity of approaches to flexibility and highlights the advantages and barriers associated with each [4].

Implicit flexibility relies on price signals to encourage consumers to adjust their energy consumption. In manual implementations, consumers are required to voluntarily respond to dynamic pricing signals, shifting their energy use to off-peak times [1, 6]. While this approach can reduce costs and promote energy efficiency, it often leads to inconsistent participation due to the cognitive burden and behavioural challenges faced by consumers [6, 8]. Explicit flexibility provides incentives to consumers if they modify their energy consumption according to system needs. In manual implementations, consumers must adjust their energy usage as requested by the grid operator by switching on or off appliances. Despite offering clear financial benefits, this approach often faces barriers related to trust, communication challenges, and participation costs [5, 7].

Automated flexibility leverages smart devices to manage energy consumption without requiring active consumer involvement. By automating responses to grid signals, whether they are prices or incentives, this approach addresses key barriers such as effort and uncertainty, enhancing the appeal of flexibility schemes for residential customers [2, 8, 14]. Automation addresses the challenges often associated with manual responses [11, 12] by enabling seamless integration of flexibility into daily energy use. AF could not only reduce the burden on consumers but also increase reliability and predictability for grid operators. By focusing on AF, this study highlights its potential to overcome the limitations of manual schemes and its ability to provide appealing value propositions for residential customers. ***Table 1*** complements this information by offering specific examples of flexibility schemes applied to different devices, including PV systems, electrical heating and cooling, and EV chargers, as analysed in this study.

Table 1. Flexibility Schemes in Analysed Devices

	Implicit Flexibility		**Explicit Flexibility**	
	Manual	**Automated (AF)**	**Manual**	**Automated (AF)**
PV Systems	Consumers manually shift appliance usage (e.g., running washing machines in the morning) to align with solar generation.	A programmable smart plug sets appliance operation at a time when self-generation is greater.	Consumers respond to rebates for feeding excess solar energy back to the grid.	Automated systems store excess solar energy in virtual batteries and sell it back to the grid if so required.
Heating/ Cooling	Consumers adjust thermostats manually to avoid peak prices.	Smart thermostats optimise temperature settings based on dynamic prices.	Consumers lower demand during critical peaks in exchange for financial incentives.	Smart HVAC systems adjust in real-time to grid needs for financial rewards.
EV	Drivers charge vehicles during off-peak hours based on electricity price signals.	Automated EV chargers delay charging until electricity prices are lowest.	Drivers manually adjust charging times to benefit from incentive-based programs.	Automated chargers provide flexibility by charging vehicles when the grid has excess capacity or by obtaining the energy stored in the EV (vehicle-to-grid).

3. METHOD

Aiming to unveil the motives and barriers of residential consumers for enrolling in AF, a phenomenological method was employed [12]. This is a suitable method because the lived experience of individuals needs to be coordinated with technologies "to ensure a successful introduction of energy flexibility" [15]. By understanding the gains and pains that this equipment has for consumers, we can infer appealing value propositions for participating in AF. In-depth interviews were held with residential consumers who are potential participants in AF schemes, as they possess smart programmable and/or interruptible electric devices, such as electric vehicles, heat pumps, smart thermostats, or PV systems. Consumers were asked to describe (1) their perceptions of energy and the energy transition; (2) their motives for acquiring the smart devices and their situated experience with it, focusing especially on the pains encountered; and (3) after explaining what AF is, they were probed about the anticipated gains and pains they saw in this scheme.

Purposive sampling was used to select informants [16]. We focused on three countries (Spain, Italy, and France) for convenience reasons. This fieldwork was done as part of the demonstration deployment carried out in the EU-funded project BeFlexible, where the value propositions for encouraging participation in flexibility would be later tested. A focus on these countries also allows for a better understanding of the local context, namely the main cultural, social, technical and economic characteristics; this understanding helped researchers interpret the interviews. The coordinators of these demonstrations assisted with the recruitment.

The informants were, however, mostly male, middle-aged, highly educated. This is not surprising as this profile is characteristic of owners of EVs, PVs or aerothermia [15, 19]. Although purposive sampling is deemed appropriate when the research is exploratory, it should be kept in mind that the findings may not generalise to all populations and that a testing method (i.e., experiments) is necessary to validate the behavioural response to the inferred value propositions.

Nineteen interviews were held, 5 in France, 4 in Italy and 10 in Spain. The interviews lasted between 45 and 60 minutes and were conducted online. Saturation was reached with interview 12, but more interviews were conducted to ensure the variability among informants (**Table 2**). We followed strict ethical guidelines for informed consent and personal data protection. Thematic analysis was used for the analysis [20]. The first author read each transcript several times. The analysis showed that the motives for enrolling in EF were tightly linked with the main pains they encountered in the use of their current equipment. This led us to differentiate between PV systems, electrical cooling/heating users, and EV charger users; drivers and brakes for AF were examined for each of this equipment. The analysis was then discussed with the second and third authors until the core themes in the findings stabilised. **Table 3** provides sampled quotes of the main findings**.**

Table 2. Description of informants

Pseudonym	**Gender**	**Equipment**	**Country**
Abel	M	Solar water system, swimming pool	Spain
Alberto	M	EV+ PV production for community use	Spain
Antoine	M	PV, EV	France
Cristian	M	PV	Spain
Diego	M	PV plug-and-play + home energy storage	Italy
Francisco	M	EV, PV, HC, Aerothermia	Spain
Giacomo	M	PV, battery, hybrid car	Italy
Henri	M	PV, EV	France
Lois	M	EV	France
Marion	F	PV, EV	France
Nicolás	M	Solar water system, swimming pool	Spain
Paloma	F	EV	Spain

Pedro	M	EV	Spain
Pierre	M	PV, EV	France
Priscila	F	Electrical heating/cooling	Spain
Rafaela	F	EV	Spain
Rodrigo	M	PV + swimming pool	Spain
Sandra	F	PV, battery	Italy
Serena	F	PV, battery	Italy

4. FINDINGS

4.1. Users of PV systems

The installation of PV systems is driven by a desire to take advantage of natural, free, replenishing resources that can reduce consumer bills and emissions. As Henri said: "If we have thousands of hours of sun, why don't we make the most of it? I prefer this system to gas. We are trying to get rid of fossil energies". However, users of PV systems report “wasted energy”, as they call it, as their main pain. Most users acknowledge that they are not able to use all the energy self-produced for their consumption since some appliances are used in the afternoon or evening, or high-consuming appliances are not electrical (notably, gas-powered heaters). The difference between generation and consumption is perceived as "wasted energy" or energy that they lose. Consumers are forced to buy energy from the grid, which limits their aspiration to self-sufficiency. Moreover, although the non-used energy feeds the grid, the prices obtained are widely considered too reduced. This infuriates consumers who consider the pricing system unfair: they buy energy at a much larger price than the price at which they sell. These reasons explain their perception of “waste” or “loss”. To reverse this situation, they try synchronising their use of appliances with production by changing their practices (e.g., running the washing machine in the morning). However, these changes create discomfort as they may interfere with family routines or family needs.

These pains create opportunities for AF. Appealing value propositions that amplify the value sought when installing PV systems could facilitate their enrolment in these schemes. Value propositions that ensure that their self-produced energy stays at home, allowing consumers to "make the most" of their self-produced energy and enable self-sufficiency, can entice consumers to enrol in AF.

The interviews reveal three value propositions that can enable consumer engagement with AF. The first one is retrofitting and interconnectivity. Users may be offered smart appliances that can be synchronised with their production or offering smart systems that synchronise appliances with their PVs. These appliances may be offered at a discount as part of the incentives for explicit flexibility. This retrofitting taps into the reported desire to replace gas-operated heating with electrical heating to make the most of their production. Antoine, for instance, shared his plans to replace their current heating system with solar-powered thermal energy. Similarly, Diego and Rodrigo want to get rid of gas and replace the gas-powered cooker with an induction cooker or the gas boiler with a heat pump. Marion wants to couple its water heater with her PVs with a smart household system.

A second value proposition taps into the dissatisfaction reported by consumers regarding the feed-in tariffs. Informants acknowledge being more interested in discounts on their tariffs than in direct repayments of the power fed into the grid. One way of providing these discounts is by means of "virtual batteries" or "solar wallets". In this scheme, consumers are credited with the kWh self-generated; these kWh can be later used to offset their consumption. Thus, the energy generated and not used can be quantified and "stored" in an account that can be used by consumers at times when their own production is not sufficient to power their equipment. Even when solar wallets credit half of the amount aggregated or when the discount is reduced, it seems a more appealing value proposition for consumers than the current feed-in scheme.

Finally, the generalised perception that the payments are negligible motivates consumers to be more inclined to share their power with significant others or with neighbouring buildings than to sell it back to the grid. Giacomo, for instance, recognises being more interested in donating his production to the local school than to the grid. Similarly, Diego and Marion acknowledge their interest in a scheme where their unused production goes to the neighbourhood or to their family and friends. A third value proposition is to offer "shared wallets" so that the energy produced is credited as in the previous one but can be “transferred” to other consumers so that they can discount their energy bills. However, other informants are not inclined to donate or share, be it because they perceive their neighbours can afford the energy expenses (Nicolás) or for fear of creating a free-rider problem. This is how Antoine puts it: "If you donate, you reduce their motivation to reduce their consumption, and for me, this is not good. I think that people must learn to reduce their consumption, not just look at the price". Designing mechanisms that ensure the perceived fairness between givers and receivers of solar energy is then fundamental in this third strategy. Specifically, it seems fundamental that these sharing systems avoid potential rebound effects among receivers: as they would not pay for part of their energy supply, they may not have incentives to be more efficient in their energy consumption.

4.2. Electrical heating and cooling

The main benefit motivating consumers to install programmable electrical heating/cooling systems is to avoid wasting energy. Consumers choose to program their equipment to adjust it to the times they are at home and to set a “reasonable” temperature. Avoiding energy waste by being more efficient is also a value proposition that blends environmental and economic motives since, for consumers, avoiding energy waste is akin to reducing bills and emissions. AF can provide benefits that are aligned with this consumer motive, such as implicit and explicit flexibility. The first value proposition for proposing AF is that it provides reassurance that they will have lower bills because energy is not wasted: heaters will be on when they need it and for the comfortable temperature desired. Also, smart heaters can regularise consumption and make it steadier. For consumers such as Zoe, steady consumption implies more control over energy expenses so that they can anticipate future energy costs.

A second value proposition should emphasise the convenience offered by smart heaters. Although manual programming does not entail great monetary or time costs, consumers perceive it as a burden. De-burdening consumers from this task by granting control of programming to an external party could be then another motive for enrolling in AF.

A final value proposition can be based on their concerns about grid stability. The more energy-literate informants are aware of the tensions that fluctuating energy consumption may pose to the grid. Several informants, such as Antoine, Henri, Marion or Priscila, would be willing to enrol in AF and provide control to third parties just to ensure that the grid is stable and there are no power cuts.

4.3. Electrical vehicle charging

The reported motives for acquiring or renting an EV are also a combination of self-centred (savings and convenience) and other-centred concerns (reducing emissions and noise, thus raising the quality of life in the neighbourhood). Driving an EV provides greater personal convenience to urban users as they can enter free-emission zones and get discounted or even free parking slots in public buildings. This was the main motive for Abel, Paloma, Rafaela or Veronica to acquire an EV. It also produces greater societal comfort as EVs not only emit less emissions but are also less noisy. For instance, Giacomo said: "When I go out, I go out in electric, and it seems to me like a contribution to the condominium. I like to go on the street and hear the traffic as a hum and not as a tram tramp. It's not just energy savings; it's cleaner air and less noise". Driving a quieter, non-fuming car is, for him, a way to improve the quality of life in the city. Similar reasons are provided by Francisco or Paloma.

Two are the main pains in using EVs: the limited autonomy for long-distance trips and the difficulties in charging. We will describe the second one since it may be the basis for providing AF. Charging practices are very different depending on the location of the charger or the tariffs. Some informants charge the car free of any costs at their employer's premises. Other consumers charge the car at home, but their tariffs make them oblivious to the time of charging. This is the case of Paloma and Alberto. Paloma enjoys a tariff with 50 free hours per month; these are the hours she chose to charge the car. Alberto has a time-invariant tariff. None of them demonstrate their concern about charging prices or inconveniences.

Most informants avoid charging in public chargers for several reasons: it is inconvenient, and, more importantly, they are afraid of battery damage. Charging in a public charger is inconvenient because each of them is operated by a different company. Consumers must then download the corresponding app, learn to use it and input their credit card details. Not only does it take time to charge the car, but consumers must spend time preparing at each charging point.

Most informants, then, charge their EVs at home, usually at night. Charging the car at home is enabled by the provider app. Yet, the limited number of functionalities that the app offers is a pain for consumers. Although the app usually enables the setting of charging times, consumers are not aware of the prices at these times. This creates uncertainties as consumers are not sure how much they would be for each charge. Some consumers use another app to identify the best night hours for charging the EV, investing a considerable amount of time to decide which times are better to charge their cars. For this, they would be willing to use a service that automates the charging, considering real prices. As most consumers leave their car overnight, they do not care much when the charging occurs as long as it is ready when they need it.

Smart chargers enable the provision of AF, both implicit and explicit. The interviewees are willing to use a smart charger to reduce their bills (implicit) or give control to a third party to operate the smart charger, adapting it to the grid needs in exchange for a discount (explicit). This is the first value proposition for consumers that aligns with the benefits sought: it provides a monetary value and increased comfort since it de-burdens consumers from monitoring and adjustment.

Yet, consumers require reassurance that the battery will not be damaged due to ongoing interruptions in charging. Anticipation of battery damage is the main barrier to engaging in AF. Informants suggest insights that would make the value proposition more appealing. First, consumers should be allowed to set the percentage of charging required. Other informants require that the service include a form of battery insurance so that in case of damage, consumers will be granted a new battery. Finally, other consumers, such as Pedro or Alberto, propose battery leasing. In this case, consumers would be given a new battery for their car that will be charged flexibly; once the consumer abandons the service, the battery is returned to the operator.

Table 3. Pains in the use of systems and value propositions for AF

PV systems	Sampled quotes
Pains in the use of PVs	
“Wasted” self-generated energy	"I see that I produce a lot of energy that goes into the grid. Paradoxically, I produce, but financially, little is returned to me" (Sandra) "Utilities are making money with this. They pay me 5, and they sell at 25, so they are making a giant profit. This is not fair at all. If I made the investment and I am

	producing the energy, I deserve better compensation. This cannot go on this way: they earn money, and I don't." (Rodrigo) "The feed-in tariffs are not interesting. It is better to calculate how much you need to produce and to match what you need to consume during the day" (Pierre)
Value propositions for AF	
Your energy stays at home	"The point is not just to lower the bill. I want to make the most of the energy that I produce" (Sandra) "If I am producing that much that is going to the grid, then I increase the temperature of the heater to retain the energy at home, or I speed up the charging of the EV" (Francisco) "It would be super useful for me. If I could automatise it so that the washing machine runs when there is more production or the production goes to charge the e-scooter, it would be great. Sometimes I am not at home, and I cannot do it manually" (Cristian) "For instance, powering a water heater so that it heats water in the morning so that it takes less energy to use it at night. This does not exist, and I think it would be super helpful" (Rodrigo)
Solar wallets and shared wallets	"I don't think it is right that when I sell energy, I am taxed again. I am taxed twice! I would rather have kWh credits to use when I need them to cover my night consumption, say. Even if they say for two kWh produced, we will give you one, it would be more appealing than the feed-in tariffs" (Henrie) "I would like it to be a discount on my bill depending on how much I feed into the grid. I would like it to be a credit for the next bill. If I get 3 or 4 euros, I'd prefer it to go on my bill so that it accumulates for when it's my turn to pay" (Nicolás) "If you donate, you reduce their motivation to reduce their consumption, and for me, this is not good. I think that people must learn to reduce their consumption, not just look at the price" (Antoine)
Electrical heating and cooling	**Sampled quotes**
Pains in the use of EH&C	
The burden of manual programming	"I spend much time doing manual adjustments. Much time" (Francisco) "I've adjusted the heating times to turn them off 15 minutes before we get up and to have no heat when we're not at home. I haven't done any smart advanced management yet, but I know they exist. However, I still have the old thermostat with day-by-day, pre-time programming. I would like to think less about it; I would like it to work automatically, to turn off the heating when we go out and turn it on when we are about to return, to turn it off when the windows are open... I'm careful, but you need some help here. I would like everything to work automatically, but if I have to be on it, it becomes a problem. If it becomes an extra concern, instead, it becomes a problem" (Giacomo) "We cannot set the temperature; we can only set it on and off; we can decide how much to heat, but we cannot set the temperature. We have a reversible conditioning system, but we try to be very careful. If the person doesn't or can't take the time, then you just put the temperature on for the entire day. I can control the heating manually so we can decide which time they start and stop; it is not digital. You have actually to do it, so having something nicer and easier would be interesting" (Louis)
Value propositions for participating in EF	
Lower your bills Predictable	"If we [consumers] can maintain a steady temperature, adjustable by one degree, there will not be peaks in demand. This is good for grid planning, and we [consumers] should be rewarded because we are more predictable" (Priscila)

and steady bill Liberate yourself from the hassle	
Electrical vehicle charging	**Sampled quotes**
Pains in the use of EVs	
Unpredictable pricing and burden of manual programming	"I select the power, depending on the state of charge. I calculate how many hours I have left and leave it overnight charging, and that's it. I wait for it to charge until just before I get in the car so that when I go to get in the car, the battery is warm and doesn't consume so much" (Abel) "The price can be very different. Last time, it was 0.8 per kWh, while other times, it is 0.2, so they change a lot. It makes it very difficult to know what you are going to pay" (Lois) “I can set up the times, but it does not automatise charging taking into account the time-variant tariffs. It would be great if it did" (Abel). “Slow charging is even better as it protects the battery more" (Pierre)

5. CONCLUSIONS

In this study, we explained the characteristics of automated flexibility for providing implicit and explicit flexibility, which is potentially more appealing to consumers due to its ability to circumvent the barriers associated with manual responses while providing gains for consumers. Through a phenomenological study involving in-depth interviews with residential consumers in Spain, Italy, and France, we identified distinct value propositions for different types of equipment: maximising resource utilisation for PV systems, avoiding energy waste for users of electrical heating and cooling, and ensuring convenience and comfort for EV users. These value propositions, combined with monetary incentives in the case of explicit flexibility, emerged consistently across the three countries, indicating their potential to appeal across diverse national contexts.

Our findings suggest that economic incentives are merely one of the possible gains offered to consumers. This aligns with past critiques that existing approaches within smart energy often overemphasise the importance of economic motivation in assumptions about energy consumers' behaviour. Many smart grid designs are guided by a flawed understanding of individual energy consumers as efficient and well-informed micro-resource managers who exercise control and choice over their consumption and energy options. Our insights, therefore, provide a basis for developing more nuanced consumer engagement strategies in flexibility provision, a need identified in past studies [19].

By addressing the key pains and barriers identified in our study, such as the perceived unfairness of feed-in tariffs and the manual effort required for energy management of thermostats or EV chargers, AF schemes can offer more appealing value propositions. For PVS users, strategies like retrofitting and interconnectivity, virtual batteries, and shared wallets were suggested. For users of electrical heating and cooling, the focus was on automated systems that increase energy efficiency and offer convenience. For EV users, smart charging solutions that ensure battery protection, convenience and monetary benefits were highlighted. These value propositions amplify the value sought by consumers when acquiring flexible appliances.

6. FUTURE RESEARCH

Future research should focus on testing these value propositions across different demographic and cultural contexts to validate their broader applicability. Investigating the specific barriers and drivers for each type of equipment across regions and sociodemographic segments will provide deeper insights into consumer behaviour. Additionally, exploring the long-term impacts of these value propositions on energy consumption patterns and grid stability will be crucial.

Further studies should also examine the role of non-economic incentives in promoting consumer engagement and the potential for integrating behavioural insights into smart grid designs. This includes understanding how factors like convenience, environmental consciousness, and social influences can drive participation in embedded flexibility schemes. The integration of advanced technologies, such as AI-driven energy management systems and predictive analytics, could also be explored to enhance the effectiveness of these schemes.

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