Què funciona contra el canvi climàtic?

Report

What works to improve energy consumption habits of households?

Policies and programmes for reducing and shifting energy demand

ivàlua
Institut Català d'Avaluació de Polítiques Públiques

COAMB
Col·legi d'Ambientòlegs de Catalunya

Generalitat de Catalunya

Què funciona contra el canvi climàtic?

What works to improve energy consumption habits in the residential sector?

Policies and programmes for reducing and shifting demand

Final report:
October 2025

Thematic area:
Energy

Project promoted by:
Ivàlua (coordination), **Department of Economics and Finance, Department of Territory, Housing and Ecological Transition and Col·legi d'Ambientòlegs de Catalunya**

Summary prepared by:
Jacint Enrich – Energy Research Group, Barcelona School of Economics (BSE)

Acknowledgments:
The author would like to thank the research assistants Uxue Arregui and Andrea Jausàs, members of the Energy Research group at the Barcelona School of Economics for their contributions to the project.

The author also acknowledges support from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 101001732 – ENECML, awarded to Mar Reguant).

Revision and support:

Steering group: Maria José del Blanco and Xavier Soto (Department of Economics and Finance); Leonardo Bejarano, Gisela Torrents and Júlia Rubert (Department of Territory, Housing and Ecological Transition); Salvador Samitier and Maria Visitación Garcia (Department of Agriculture, Livestock, Fisheries and Food); Verónica Serrano (Col·legi d'Ambientòlegs de Catalunya); and Anna Segura and Cristina Ferrer (Ivàlua).

Expert group: Olga Alcaraz (Polytechnical University of Catalonia), Jeroen van den Bergh (Institute of Environmental Science and Technology - ICTA-UAB), Maria Crehuet (Associació de Micropobles de Catalunya), Irene González (Aliança contra la Pobresa Energètica), Albert Puigvert (Associació d'Iniciatives Rurals de Catalunya), Ana Romero (Àrea Metropolitana de Barcelona), Jordi Teixidó (University of Barcelona) and David Villar (Catalan Institute of Energy).

The views presented by the author do not necessarily coincide with those of the promoting bodies.

Què funciona contra el canvi climàtic?

Evidence synthesis and knowledge transfer project to improve climate change mitigation and adaptation policies.

A project by:

ivàlua Institut Català d'Avaluació de Polítiques Públiques

COAMB Col·legi d'Ambientòlegs de Catalunya

Generalitat de Catalunya

Què funciona?

List of contents

1. Introduction

Energy consumption is by far the largest source of emissions of greenhouse gases (GHG), and is responsible for approximately 75% of the world's total emissions. Of this amount, 11% derives from the residential sector.[1] In Catalonia, the figures conform to this global trend: energy consumption represents 71.6% of total GHG emissions, of which the residential sector contributes 13.8% (Catalan Energy Institute, 2022). Therefore, reducing household energy consumption, especially during the hours when consuming energy is more expensive and causes higher levels of pollution, is essential in the attempts to move towards a decarbonized economy.

In order to improve energy consumption habits, it is necessary, first of all, to inform households of the energy services they use and the amount of energy they consume. In addition, households must have both the capacity and the will to modify their energy consumption habits when external conditions change: for example, in response to variations in energy prices.

With the aim of contributing to the design of effective policies and programmes, this document presents a synthesis of the most recent empirical evidence on the effectiveness of different instruments that aim to promote changes in energy consumption habits in the residential sector, known as demand response programmes. These include both information programmes and interventions based on economic incentives, either through direct subsidies or through energy pricing tariffs. The document not only presents results in terms of efficiency but also seeks to address potential equity issues wherever evidence is available.

The evidence review focuses on studies that use experimental or quasi-experimental methods to evaluate the impact of interventions, and includes experiences from countries that are, to a large extent, comparable to Catalonia. However, the idiosyncrasies of each context must be taken into account when extrapolating the results.

2. Motivation

To reduce the emissions associated with household energy consumption, it is necessary either to lower consumption or to increase the use of cleaner generation sources. The cost of generating electricity varies over the course of the day, since, depending on the particular time, different production technologies with very different marginal costs and emissions are activated. Additionally, electricity demand fluctuates considerably at different times of day, with peak demand periods requiring the use of more expensive and polluting sources.

[1] Source: Climate Watch: https://ourworldindata.org/ghg-emissions-by-sector

The rapid expansion of renewable energies, which generate electricity in a variable manner but with low marginal costs and without producing carbon emissions, makes it more necessary than ever for demand to adapt to market conditions and environmental criteria (Harding and Sexton 2017). This implies, among other things, that households consume electricity at times when it can be derived from cleaner sources. However, if the prices paid by consumers are constant, and therefore do not reflect these changes, their energy demand will be excessive at times when electricity is expensive and polluting, and insufficient when it is cheaper and cleaner (Joskow and Wolfram 2012). The aim of demand response policies is precisely to improve the energy habits of households, mainly through the introduction of dynamic pricing systems that reflect the true cost of producing electricity and incentivize households to consume at times when this consumption causes less pollution (Boiteux, 1960).

The **electricity tariff** is the pricing plan that establishes how much a consumer pays. Typically, these tariffs include the cost of energy consumed, the power contracted, regulated costs (access tolls and system charges) and taxes. We refer to **dynamic** tariffs or **dynamic prices** when the price of electricity paid by the consumer varies over time.

Despite the potential economic and environmental advantages of dynamic pricing, most consumers around the world still pay fixed price tariffs. For example, in 2014, less than 1% of American households had dynamic tariffs (Harding and Sexton 2017), a percentage that has changed little over the last decade. An exception to the predominance of fixed tariffs is found in Spain. Since 2015, families who have contracted the regulated tariff have paid, for the part corresponding to the energy cost, hourly prices determined by the wholesale market. In addition, in June 2021, the central government implemented an hourly tariff policy that applied to the part of the regulated costs, regardless of the energy cost.

One of the main reasons why governments and companies may be reluctant to implement dynamic pricing is that, if the conditions are not right, electricity demand reacts poorly to price changes.[2] On the one hand, if it is costly to inform consumers about both the prices that apply at any given time and the specific consumption of each household appliance, they are unlikely to react to price changes. Furthermore, even if consumers are accurately and thoroughly informed, it may be difficult or inconvenient for them to adjust their consumption, especially when coordination of tasks is required among the different members of the family. For this reason, it is important to be able to complement dynamic pricing policies with information

[2] In fact, in their analysis of the introduction of dynamic prices for consumers of the regulated tariff, Fabra et al. (2021) find an average elasticity of zero. The authors argue that these results may be due to the low variation in prices, together with the high cost of obtaining information. It should be borne in mind that the study period preceded the energy crisis, and so the results now might be different given the drastic increases in electricity prices during 2022.

programmes and technologies that help break down information and action barriers. These measures can be focused both on shifting consumption to time slots when electricity production is more economical and less polluting, and in general on reducing the total energy consumption of households.

Another reason why policymakers hesitate to introduce dynamic pricing is its possible distributional effects; if households with lower incomes have less room for manoeuvre to adjust their consumption to price variations, they may face higher energy bills when they move from a fixed-price tariff to a dynamic one (Cahana et al. 2023).

3. Questions that guide the evidence review

The literature review is motivated by the desire to understand the effects of different interventions aimed at modifying household energy consumption patterns, and how these measures have affected households' well-being. The following questions are addressed:

1. What are the main public policy instruments that have been used to reduce or shift household energy demand?
2. Which instruments have been found to be most effective, and what are the key elements of their design that contribute to their effectiveness?
3. Can new technologies increase the effectiveness of the instruments analysed?
4. Do the effects differ according to household type or other relevant factors?
5. Are there interventions that can generate counterproductive or undesired effects?
6. Are there examples of good practices that can be taken as models to improve the design of demand response policies in Catalonia?

4. Policies included in the review

This synthesis focuses on programmes aimed at reducing GHG emissions caused by energy consumption in the residential sector, by promoting the following changes in consumption patterns:

1. **Reducing consumption**: lowering total energy consumption by reducing the demand for energy services such as lighting, heating and cooling, or the use of household appliances.
2. **Shifting consumption**: maintaining the same level of energy services but changing the time of day when energy is consumed to cheaper and less polluting times.

Policies that aim to facilitate and incentivize these changes in consumer habits are called **demand response policies**. They can be divided further into **information-based** measures, which use information, education or persuasion to influence consumption habits, and **price-based** measures, which aim to modify household behaviour through economic incentives.

The first block of this synthesis analyses **information programmes** designed to overcome the gaps in information that make it difficult for households to reduce or modify their energy consumption. These include both **energy consumption reports** and **personalized advice**, which may be accompanied by financial incentives.

The following two blocks review the evidence on the effectiveness of programmes that introduce **financial incentives** to promote changes in energy consumption. Specifically, they analyse, on the one hand, **direct subsidies** to households offered as a reward for reducing energy consumption below a pre-established threshold, and, on the other, interventions based on the introduction of **dynamic price tariffs**, which vary in several dimensions such as the magnitude of the price variation, the frequency of changes, or the duration of the new tariff.

The final section explores ways in which programmes to introduce new technologies can serve as a good complement to the pricing mechanism when households have the willingness, but not the ability, to adjust their consumption. Specifically, in this synthesis we will focus on the additional effects of **energy monitors** and **adjustable thermostats** when they accompany the introduction of dynamic pricing.

Policies and programmes that aim to reduce emissions from the residential sector by improving energy efficiency will not be covered in this review, as they were already analysed in the previous synthesis "What works to improve energy efficiency of buildings? Policies and programmes for encouraging the adoption and use of efficient technologies". Policies and programmes aimed at promoting the installation of solar panels are also excluded. The high initial investment, the differences between solar and non-solar tariffs and the fact that consumers also become producers mean that the mechanisms by which electricity consumption is modified are totally different, and fall outside the scope and the objectives of this synthesis. [3]

Given the scarcity of rigorous evaluations of the impact of the effectiveness of these policies in Catalonia and Spain as a whole (in fact, only three were identified), we have included evaluations and reviews conducted in other geographical settings, mainly the US and to a lesser extent in Europe. In total, 33 primary studies have been included. Nine studies evaluate the effects of interventions that provide information through energy consumption reports, and two more do so through personalized advice. Three studies evaluate the impact of subsidies as an economic incentive; one of them also simultaneously analyses the provision of information, and is therefore included in both categories, although it is counted only once in the total. Eighteen

[3] In fact, becoming an electricity producer automatically entails being subject to dynamic prices for the energy sold. However, as of today, the evidence on how such tariffs affect household behaviour remains limited.

studies analyse the effects of introducing dynamic pricing. Of these, ten complement the programmes with the introduction of new technologies, and two more assess the effect of these technologies without the corresponding change in tariff.

5. Measures of effectiveness

The main variable used to measure the effectiveness of policies is energy consumption, and more specifically electricity consumption. This is because the aim of demand response policies, in addition to reducing consumption, is to shift consumption to times of day when consuming energy is more economical and causes less pollution; this possibility only exists in the case of electricity, which can be obtained from different energy sources including renewables, most of which cannot be switched on and off on demand. [4]

Additionally, in some cases, variables related to **thermal comfort** are also included: for example, the time an air conditioner is running, or changes in ambient temperature.

6. Literature review

6.1. Information programmes for reducing household energy consumption

A first set of programmes attempts to change household consumption patterns by **providing** families with **information** on their energy consumption and on the benefits of reducing it, and advice on how to do so. This information may come in the form of a **periodical report** sent to households or through **face-to-face advice** as part of an energy audit.

6.1.1. Are energy consumption reports effective?

The first experimental studies on the effectiveness of interventions aimed at reducing energy consumption in the residential sector focused on programmes that addressed the issue of information by providing households with **personalized energy consumption reports**. Known as home energy reports (HERs), they often also offer a comparison of consumption with other households of similar characteristics or include a series of tailored recommendations to help families save energy. Nine of the studies reviewed analyse the effect of this type of reports on household electricity consumption (Table 1).

Table 1. Evidence regarding the effectiveness of HERs

Study	Country	Intervention	Variable	Result

[4] The management of renewable energy intermittency is changing drastically with the introduction of batteries, which will be able to meet demand needs at any time of the day.

Allcott (2011b)	United States	Periodical reports with peer comparison and saving tips	Electricity consumption	-2% on average
Allcott & Rogers (2014)	United States	Periodical reports with peer comparison and saving tips	Electricity consumption	Decrease in the effect found in Allcott (2011b) of 10-20% per year
Asensio & Delmas (2015)	California (United States)	Weekly information on monetary savings	Electricity consumption	No significant effects
		Weekly information on the damaging effects on health and the environment		-8.2%
Byrne et al. (2017)	Melbourne (Australia)	Fortnightly information + web portal	Electricity consumption	Baseline consumption Q1: +11.7% Baseline consumption Q5: -11.0%
				Households that overestimate: +6.3% Households that underestimate: No significant effects
Costa & Kahn (2013)	United States	Periodical reports in households of different ideologies	Electricity consumption	Liberals: -2.4% Conservatives -1.7%
			Probability of abandoning the programme	15 pp higher for conservatives
Dolan & Metcalfe (2015)	United Kingdom	Periodical reports with social comparisons	Gas consumption	-4.4%
		Periodical reports with peer comparison and saving tips		-10.8%
Jessoe et al. (2017)	California (United States)	Two-monthly information on water consumption	Electricity consumption	-1.3% / -2.2%
Pellerano et al. (2017)	Quito (Ecuador)	Report with peer comparison and saving tips	Electricity consumption	-1%
		Report with peer comparison and saving tips + information on potential monetary savings		-0.5%
Schultz et al. (2007)	California (United States)	Reports with peer comparison sent to households with different baseline consumptions	Electricity consumption	Above average: -5.6% Below average: +8.5%

In general, HERs are associated with falls in gas and electricity consumption. The intensity of these falls is highly variable and depends on many factors: the content of the reports, the frequency with which they are received, the total number of reports received, the time since the end of the intervention, previous electricity consumption and the individuals' beliefs regarding the amount they consume.

The first large block of experiments corresponds to studies in the US, where the company Opower, in conjunction with a number of energy suppliers, sent reports to households across the country. In a seminal study, Allcott (2011b) assessed the effects of the programme, one of the largest carried out at that time (17 experiments in different states involving 600,000 households). The energy consumption reports contained two key components: first, a comparison of the consumption in households that received the reports and in households of similar characteristics and geographically close by that did not receive them; second, advice on energy efficiency that took into account the baseline energy consumption and the households' characteristics. The short-term effect of receiving the reports was an average reduction in electricity consumption of 2%, an effect that the author estimates would be equivalent to what one would expect from an increase in the price of energy of between 11% and 20%. Furthermore, one of the 17 experiments found that sending the reports monthly instead of quarterly increased the reduction in electricity consumption by an additional 0.5 percentage points.

Allcott and Rogers (2014) investigated whether the effect found by Allcott (2011b) disappeared when the period analysed was extended beyond the moment when the reports were discontinued. The authors found that the effect persisted, although it gradually decreased when the reports were discontinued two years after the start of the project. Specifically, the authors observed a decline in the effect of the order of 10-20% per year. This decrease in the effectiveness of the reports over time suggests that repeated mailing is a necessary condition in the short term, at least until households adopt energy-efficient measures or consolidate consumption habits.

With regard to the contents of the reports, Dolan and Metcalfe (2015) found that adding a social comparison could significantly increase their effectiveness. In a study on gas consumption, they found that households whose reports included this comparison achieved a reduction in consumption of 4.4% compared to households whose reports did not have this component. The effect was even greater when social comparison was combined with specific advice on how to reduce consumption, reaching the figure of 10.8%.

Several studies have examined in more detail the possible heterogeneous effects of HERs that include social comparisons. Regarding consumer characteristics, on the one hand, Costa and Kahn (2013) found that the ideological position of the consumers receiving the report can influence the effectiveness of the intervention. Continuing with the Opower experiments, they found that households defined as liberal and environmentalist had a more efficient baseline consumption and, in addition, were more responsive to the reports. On the other hand, several studies concluded that a large part of the reduction in electricity consumption came from those households that consumed above average levels before receiving the report. These households, in addition to having greater room for manoeuvre, learn that the social norm is to consume less and try to adapt. For example, Allcott (2011b) found that for households in the highest decile the drop in electricity consumption was 6.3%, while there were no significant effects in households in the lowest quintiles of energy consumption; Byrne et al. (2017) found even more striking results in Melbourne, where individuals in the highest quintile reduced their electricity consumption by 11.7%. Similarly, Schultz et al. (2007) found that California households that consume more than the average responded to the provision of information with a daily reduction of 5.6%, but that in households with below-average consumption it increased by 8.5% after receiving the reports.

The fact that peer comparison increases the consumption of households that were consuming below the average reflects a phenomenon known as the *boomerang effect*. Byrne et al. (2017) found evidence that the boomerang effect depends not only on the consumption itself, but also on households' beliefs regarding their consumption. First, they found that only 25% of households could correctly identify the quintile in which their consumption is located and, therefore, that most households either overestimate or underestimate their consumption. As a result, households that had overestimated their consumption increased it when the report showed them that it was lower than they thought; in contrast, households that had underestimated their consumption and might in principle have been incentivized to reduce it, did not do so. Returning to the study by Schultz et al. (2007), those authors found that when the report included a face icon indicating either approval or disapproval of a household's consumption, the boomerang effect was partially mitigated for households that were initially consuming below average, suggesting that it is important to establish a precedent regarding what is appropriate and what is not.

These results indicate that HERs can be effective, and at the same time less controversial instruments than taxes, emphasizing the power of policies that "do not alter the price of energy". Indeed, Asensio and Delmas (2015) found that informing households about the environmental and health benefits of reducing the GHG emissions deriving from their energy consumption could be more effective than stressing the related monetary savings, although this effect is not generalized in the literature. In a similar vein, Pellerano et al. (2017) compared the effectiveness of intrinsic and extrinsic incentives using a tiered electricity tariff from a Quito company that raised the price per kWh significantly when consumption exceeded 110 kWh per month, a rate that roughly coincided with the average household consumption. The intrinsic incentive took the form of a social comparison of consumption, while the extrinsic incentive involved a simple explanation of the monetary savings that reducing monthly consumption below the threshold would entail. In line with the results of other studies, the authors found that informing households whether their consumption was above or below the average caused a 1% reduction in consumption among households with above-average consumption; however, when this message was accompanied by an additional comment regarding the expected savings of keeping consumption below the threshold of 110 kWh, the effect was reduced by half. Together, the two studies suggest that extrinsic incentives, such as monetary savings, may not only be less effective than intrinsic incentives, but may even partially counteract their impact.

Finally, Jessoe et al. (2017) found that sending water consumption reports reduced electricity consumption by between 1.3% and 2.2%, a reduction that the authors attributed not only to the reduction of activities that require water and electricity (such as using the washing machine), but also to reductions in the use of air conditioning. These results suggest that there is a spillover effect in interventions that seek to incentivize changes in consumption patterns by appealing to social norms, and that this phenomenon can affect spheres of household decision-making other than those addressed directly.

6.1.2. Is offering households personalized advice on energy savings effective?

An alternative to energy consumption reports is face-to-face advice on energy conservation, offering similar information to that provided in reports but in a more active and tailored way. Two studies were found that combined energy audits with face-to-face advice on how to save energy (Table 2).

Table 2. Evidence on the effectiveness of personalized advice

Study	Country	Intervention	Variable	Result
Zivin & Novan (2016)	California (United States)	Audit + advice + total subsidy ($1,700 on average)	Electricity consumption	-7% for rehabilitation -31% adding tips to energy conservation
Ministry of Inclusion, Social Security and Migration (2024)	Catalonia	Audit+ advice	Awareness and use of the reduced price rate	32%
			Efficient use of energy-consuming elements	2%
			Monthly energy consumption	No significant effects
			Spending on energy	15%

The available evidence shows that personalized advice on how to reduce energy consumption can be effective, especially when offered as a complement to other measures. The study by Zivin and Novan (2016) in the US analysed the impact of the Weatherization Assistance Programme, a programme that includes an energy audit, personalized advice and improvements to home efficiency. The results show that following improvements in lighting efficiency and thermal insulation electricity consumption **was reduced** by 7% in homes with air conditioning; however, the impact increased significantly when advice was added, in which case the reduction reached 31%. This suggests that specific advice on how to maintain energy services with lower consumption can have a significant effect on final energy consumption.

In the Catalan context, a recent randomised experiment (the Training and Improvement Project to Address Energy Poverty) was implemented by the Ministry of Inclusion, Social Security and

Migration, in collaboration with the Department of Social Rights and Inclusion of the Government of Catalonia. In this experiment, alongside an intervention offering free investments in insulation, heating, boilers, and household appliances, one branch of the study provided advice aimed at improving consumption patterns and reducing energy expenditure. The authors found that receiving advice improved the distribution of energy consumption over the course of the day by encouraging families to consume more during the hours when energy is cheaper. The advice also contributed to more efficient behaviour on the use of household appliances and lighting. Together, these two behavioural changes helped to bring down energy expenditure by 15%, although no statistically significant effects were observed on total energy consumption.

6.2. Economic incentives for reducing energy consumption in households

Another way to promote reductions in consumption is to introduce economic incentives through subsidies that reward households for lowering their consumption.

6.2.1. Are subsidies effective in reducing energy consumption?

Three of the studies reviewed analyse the effects of the introduction of subsidies on electricity and gas consumption (Table 3).

Table 3. Evidence regarding the effectiveness of subsidies

Study	Country	Intervention	Variable	Result
Dolan & Metcalfe (2015)	United Kingdom	Subsidy (£100) if consumption is reduced by 30%	Electricity consumption	-8%
		Subsidy (£100) if consumption is reduced by 30% + peer comparison		No significant effects
Ito (2015)	California (United States)	Subsidy (-20% of the energy bill) if consumption is reduced by 20%	Electricity consumption	Inland areas: -4% Coastal areas: 0%
Suter & Shammin (2013)	Ohio (United States)	Subsidy ($75) if consumption is reduced by a certain amount below the monthly average for the particular home	Gas consumption	-19%
		Subsidy ($75) if consumption is reduced by a certain amount below the monthly average for the particular home + thermostat		-30%

In general, studies find that subsidies can incentivize households to reduce their energy consumption. On the one hand, Dolan and Metcalfe (2015) observed that offering a £100 subsidy to households that were able to cut energy consumption by 30% reduced their consumption by an average of 8%[5]. Similarly, in a small experiment carried out on a university campus in Ohio, Suter and Shammin (2013) found that a $75 subsidy conditional on reducing gas consumption by 283 m^3 below the household's monthly average was associated with a 19% reduction. They also found that complementing the subsidy with the provision of a thermostat increased its effectiveness, reaching reductions in consumption of 30%. This suggests that the ability to technically control consumption, together with an economic incentive to do so, is key to promoting changes in energy behaviour. [6]

The study by Ito (2015) analysed a programme carried out in California during the summer of 2005, in which households that managed to reduce their electricity consumption compared to the previous summer were rewarded with a 20% discount on their bill. The study shows that, in the inland areas of the state (where summer temperatures are higher and incomes are lower), the incentive caused a sustained reduction in consumption of 4% over several summers. On the other hand, in coastal areas, with more moderate temperatures and higher income levels, no statistically significant effects were observed. The author identified two key factors to explain these differences. The first is the climate: the impact of the incentive increased in regions with higher temperatures, where the use of air conditioning was more common and, therefore, the potential for energy savings was greater. The second is the level of income: as income rises, the response to the economic incentive falls. Specifically, the study estimates that for every 1% increase in income, the effect of the programme is reduced by 0.03 percentage points.

Finally, Dolan and Metcalfe (2015) found that, if the subsidy is combined with a social comparison of consumption, electricity consumption does not change. This result is consistent with the study by Pellerano et al. (2017), discussed in the previous section, which suggested that extrinsic incentives (such as monetary savings) and intrinsic incentives (such as the desire to conform to social norms) may interfere with each other and mutually reduce their effectiveness.

6.3. Dynamic pricing programmes to make household electricity demand more flexible

A third block of programmes includes interventions aimed at making household electricity demand more flexible through dynamic pricing, shifting it to**, ideally,** times of day when consumption is cheaper and causes less pollution. [7] Dynamic pricing can be classified into real time pricing, critical peak pricing and time-of-use pricing.

[5] This average may include both households that react to the incentive and households that attempt to adjust their consumption but fail to do so.
[6] Later on, we will look in more detail at how new technologies interact with economic incentives, focusing in particular on dynamic pricing tariffs.
[7] The hours with the lowest prices do not always coincide with the hours when electricity is generated from less polluting sources. An example of this is Spain's time-of-use tariffs, which we will examine later.

6.3.1. Are critical peak and real time pricing effective in making household electricity demand more flexible?

Critical peak pricing (CPP) combines a fixed price during most hours with occasional increases of a predetermined duration during periods of high demand, when production costs exceed certain levels and the sources used cause higher levels of pollution. These periods usually correspond to days of extreme heat, when the use of air conditioning is at its peak or, in the case of Nordic countries, during the winter months. CPP tariffs are usually preceded by a message sent to users' mobile phones warning them of the beginning of the peak period, at varying times before the event. Critical peak tariffs are the ones that come closest to truly dynamic prices (i.e., real time pricing, RTP) set according to market conditions at each particular time of day.

Nine of the studies reviewed analysed the effects of critical peak pricing on electricity consumption, while one study evaluated RTP, or indexed rates (Table 4).

Before analysing the results of the studies, it is important to mention a couple of points related to the design of the experiments that are common to most of the interventions evaluated. First, in order to encourage households to participate in the programmes, the new tariffs are devised in such a way that, in the extreme case scenario in which they fail to reduce consumption during peak periods, average consumers would not see an increase in their bill. Therefore, any reduction in consumption during peak periods would translate into savings for households. Second, in many cases the electricity contract does not allow dynamic prices to be charged to households without going through the corresponding regulatory body. This is why, in several studies, instead of being charged high prices during peak periods directly, consumers continue to pay the fixed price and, at the end of the experiment, they are credited with any reduction in consumption multiplied by the relevant dynamic price. [8]

Table 4. Evidence regarding the effectiveness of critical peak pricing and indexed rates

Study	Country	Intervention	Variable	Resulta
Allcott (2011a)	Chicago (United States)	RTP	Elasticity-price of the energy demand	-0.1
Burkhardt et al. (2023)	Texas (United States)	CPP (+500%)	Electricity consumption at peak times on the hottest days	-14%
Faruqui & Sergici (2011)	Maryland (United States)	CPP (+900%)	Electricity consumption at peak times	-20%
Faruqui et al. (2013)	Michigan (United States)	CPP	Electricity consumption during peak hours	-15%
Garnache et al. (2022)	Norway	CPP (+1200%)	Electricity consumption during peak hours	-14.2%

[8] Although in practice all these programmes ultimately amount to the same as the subsidies discussed earlier, they have been treated in separate sections due to the different practical implications of their implementation.

Gillan (2017)	California (United States)	CPP (+30%)	Electricity consumption during peak hours	-11%
		CPP (+1875%)		-13%
Hofmann & Lindberg (2024)	Norway	CPP	Electricity consumption during peak hours	-2.4% / -6.7%
Ito et al. (2018)	Japan	CPP	Electricity consumption during peak hours	-14% / -17% (and persistent)
		Moral persuasion to reduce consumption during peak periods		-8% (initial) Effect disappears with repeated treatment
Jessoe & Rapson (2014)	Connecticut (United States)	CPP – information 24h earlier	Electricity consumption during peak hours	-7%
		CPP – information 30 min earlier		No significant effects
Wolak (2010)	District of Columbia (United States)	CPP (+100%)	Electricity consumption during peak hours	-3%
		CPP (+500%)	Electricity consumption during peak hours	-9%

Allcott (2011a), in the only study analysing an indexed tariff, estimates the elasticity of electricity demand. In his study, he finds that, on average, households reduce consumption by approximately 0.1% when prices increase by 1%.

Elasticity of demand is defined as the percentage change in consumption in response to a 1% increase in price

The remaining studies, which examine CPP, found this approach to be effective in reducing electricity consumption at peak demand periods, with reductions varying between 3% and 20%. In general, there was no clear correspondence between the size of the price rise during the peak period and the reduction in consumption. Indeed, Gillan (2017) found that consumers were not sensitive to the size of the increase. An exception in which the reduction in electricity consumption matches the magnitude of the price increase is the study by Ito et al. (2018), where price increases ranging from 100% to 300% lead to corresponding consumption reductions, resulting in a constant elasticity of around 0.15.

However, not all designs are equally effective. For example, Jessoe and Rapson (2014) reported that warning consumers only half an hour in advance did not give them enough time to react. Furthermore, Burkhardt et al. (2023) found that, if messages warning of the beginning of the peak period did not include information about the price that would be applied, the reduction in consumption was insignificant. This evidence underlines the importance of designing clear information mechanisms with a time period long enough to allow consumer response.

Beyond the reduction in consumption during peak hours, several studies analyse whether households shift consumption to cheaper time slots. Garnache et al. (2022) and Ito et al. (2018) do not find a significant shift, resulting in an overall reduction in consumption, whereas Faruqui and Sergici (2011) and Faruqui et al. (2013) observed significant increases outside the peak period. For their part, Allcott (2011a) noted that, although consumption during off-peak hours increased slightly, this rise did not fully compensate for the fall recorded during peak hours, and so total consumption eventually fell.

Furthermore, there is evidence that households that switch to CPP reduce their consumption even on days when the price of electricity doesn't change (Jessoe and Rapson, 2014; Ito 2015; Hofmann and Lindberg, 2024). Although this could be attributed to the implementation of energy efficiency improvements by households, the literature suggests that this reduction is more likely due to a change in habits (Ito et al. 2018; Garnache et al. 2022).

Regarding the effects in different population segments, Garnache et al. (2022) found that it is low-income families that come off worst from the application of CPP, given their more limited capacity to adjust consumption; in contrast, high-income households, which have more scope to adapt, reduce their final electricity bills. One of the most adjustable consumptions (and particularly among high-income households) is the charging of electric vehicles. In fact, the same authors showed that households that possess electric cars cut their consumption during peak hours by 20%, compared to 14% in households that do not have these vehicles. Along the same lines, in an experiment carried out during the winter months in Texas, with prices set particularly low during the night hours, Burkhardt et al. (2023) observed that 85% of the total reduction in consumption came from changes in electric vehicle charging patterns; they detected no significant effects on heating consumption, something that is much less adjustable.

However, the study by Wolak (2010) found that low-income households included in a specific aid programme responded twice as much to incentives aimed at reducing consumption during peak hours. Their results highlighted the fact that economic incentives can also activate significant responses among groups with fewer resources, as we saw in the previous section in relation to subsidies for reducing energy consumption.

Finally, Ito et al. (2018) examined whether moral persuasion messages designed to stimulate households' intrinsic motivation to reduce consumption, could replicate the effects of a CPP programme based on economic incentives. Although significant reductions in consumption were recorded initially, these effects faded after repeated interventions. However, the authors noted that the response might reappear after a certain period of time without any interventions, suggesting that persuasion mechanisms may have intermittent or novelty-sensitive effects.

6.3.2. Is time-of-use pricing effective in making household electricity demand more flexible?

Time-of-use (TOU) pricing systems includes at least two predetermined time slots with different prices that vary throughout the day, but do not differ from day to day and are not linked to wholesale prices. The advantage of TOU is its predictability, which makes it easier for households to plan their consumption throughout the day. The disadvantage is that it does not fully reflect the real cost (either economic or environmental) of generating electricity. In what follows, we refer to peak hours as the time slot with high electricity prices, as opposed to off-peak hours when the prices are lowest.

Five of the studies reviewed analysed experimental programmes assessing the effects of TOU on electricity consumption. One of the studies also analysed price elasticity (Table 5).

Table 5. Evidence regarding the effectiveness of time-of-use tariffs

Study	Country	Intervention	Variable	Result
Enrich et al. (2024)	Spain	TOU: Peak (+200%) Off-peak (-86%)	Electricity consumption during peak hours	-9.5%
			Electricity consumption during standard hours	-6.4%
			Electricity consumption during off-peak hours	No significant effects
Fowlie et al. (2021)	California (United States)	TOU : Peak (+200%)	Electricity consumption during peak hours	Compulsory inscription: -3.5% Voluntary inscription: -16%
George & Bell (2018)	California (United States)	TOU	Electricity consumption during peak hours	Peak: -2.7% / -6.1%
			Electricity consumption during off-peak hours	No significant effects
Harding Lamarche (2016)	United States	TOU: Peak (+150%)	Electricity consumption during peak hours	0% / -15%

		Off-peak (-50%)	Electricity consumption during off-peak hours	No significant effects
Prest (2018)	Ireland	TOU	Electricity consumption	-8.9%

All the studies analysed conclude that TOU tariffs bring down household electricity consumption. Specifically, reductions in electricity consumption are observed during peak hours, without a simultaneous increase in consumption during off-peak hours.

An example of the application of TOU is the recent electricity tariff reform of the regulated costs of the electricity bill in Spain, introduced on 1 June, 2021. Drawn up by the National Commission for Markets and Competition (CNMC), this reform established three different tariffs depending on the time of day: a price rise during peak hours of 200%, mid-peak hours with a price similar to the flat rate in force prior to the reform, and a price during off-peak hours that was 86% lower. Weekends were exempt, with all hours being defined as off-peak.

Assessing the effects of this policy, Enrich et al. (2024) found generalized reductions in electricity consumption of 9.5% during peak hours and 6.4% during mid-peak hours, which, moreover, is not shifted to off-peak hours. Households also showed the same patterns during the weekend, even though the rates did not vary according to the time of day, suggesting that consumers were forming new habits. In addition, the authors used the introduction of the policy to estimate consumers' elasticity to a change in prices; the absolute values obtained, between 0.08 and 0.14, corroborated the effectiveness of TOU pricing for incentivizing demand response. [9] The authors detected a relationship between the increase in Google searches on the subject of the reform one week before the new rates were introduced and an adaptation process that lasted for three weeks and culminated in permanent changes in consumption patterns.

This evidence is consistent with the results presented by Harding and Lamarche (2016), George and Bell (2018) and Prest (2018), who also found time-sensitive tariffs to be effective in reducing electricity consumption during peak hours. Harding and Lamarche (2016) reported reductions at peak times ranging from 0 to 15%, while in a pilot experiment in California, George and Bell observed falls in consumption of between 2.7% and 6.1% with average increases of 50% in the price of electricity. For their part, Prest (2018) found an average reduction in consumption of 8.9% based on the analysis of a range of price increases varying between 40% and 170%. None of these three cases recorded a significant shift in consumption towards off-

[9] These elasticities imply that, following a 1% increase in price, energy consumption decreases by between 0.08% and 0.14%. In general, the literature finds that this elasticity is particularly low for electricity consumption, rarely reaching absolute values of 0.1.

peak hours, a finding that reinforces the idea that behavioural changes translate mainly into net reductions in energy demand, potentially leading to a loss of comfort.

Regarding the design of the tariff, in their study Prest (2018) observed that the magnitude of the increases during peak hours did not seem to have a major effect on the intensity of the response, as also noted in our review of critical peak tariffs.

Exploring the heterogeneous effects, George and Bell (2018) found that households with lower incomes reduced their electricity consumption less and, as a result, ended up paying more than they had paid before. The authors identify three possible reasons for this limited response: first, these households often have poor insulation, thus making it difficult to reduce consumption and aggravating energy poverty; second, they may have longer working hours, which limits their ability to adjust consumption schedules; finally, households with lower incomes were also found to be less aware of how the new tariffs work.

In the same vein, Prest (2018) found that out of more than 150 observable household characteristics (including income and other socioeconomic variables, types of appliances used, etc.), the only relevant factor for explaining the differences in the reductions in consumption between households was whether or not consumers were aware of the rate they were paying. This may indicate that the problems of information that prevent households from modifying their energy consumption are not limited to their unawareness of the amount they consumed, but also included ignorance of the rate they had contracted and how it worked.

Finally, in a study carried out in California, Fowlie et al. (2021) analysed the effects of introducing a dynamic pricing system in two different groups: a first group who were offered the possibility of opting in to a dynamic pricing rate, and a second group that were automatically defaulted into this programme. The results show that the response to price increases during peak hours was four times higher in the group that had opted in. These results suggest that an intervention based on facilitating the search for, and choice of, a specific rate may be a good strategy to address the information problem.[10]

6.3.3. Which pricing system is more effective: CPP or TOU?

The studies reviewed so far have evaluated interventions in which the treatment group was exposed to either CPP or TOU tariffs. However, comparison between these different instruments is not straightforward. There are two main sources of heterogeneity. The first is the fact that the experimental designs vary considerably: for each system, the tests differ in terms of the duration of the peak periods, the timing of the presentation of information, and the magnitude of the price increase. Second, the characteristics and consumption habits of households, which depend on the specific sample of each experiment, introduce another layer of heterogeneity that complicates direct comparison (Harding and Sexton 2017). To eliminate

[10] In fact, the CNMC already has its own tool for comparing rates. However, consumers need to be made aware of its existence, and they also need help in the process of selecting the optimal rate for their particular situation.

these sources of heterogeneity, in this section we analyse experimental studies that directly compare the effects of implementing a TOU or a CPP system on electricity consumption (Table 6).

Table 6. Comparison of CPP and TOU tariffs

Study	Country	Intervention	Variable	Result
Bollinger & Hartmann (2020)	Oklahoma (United States)	TOU: Peak (+200%) Off-peak (-50%)	Electricity consumption	No significant effects
		CPP Peaks (variable) Off-peak (-50%)		No significant effects
Faruqui & George (2005)	California (United States)	TOU (+70%)	Electricity consumption	-5.9%
		CPP (+500%)		-13.1%
Faruqui et al. (2012)	Connecticut (United States)	TOU	Electricity consumption	-1.6% / -3.1%
		CPP	Electricity consumption	-10.2% / -16.1%

One of the first pilots on dynamic pricing was conducted in California in 2003, after the energy crisis that hit the state between 2000 and 2001, characterized by insufficient supply and power outages. Faruqui and George (2005) observed that the introduction of TOU rates, with a price increase of 70% at specific times, was able to bring down electricity consumption by 5.9%. In the case of CPP rates, with a much higher increase (around 500%), the reduction in consumption reached 13.1%. Later, in Faruqui et al. (2012)'s pilot study in Connecticut, TOU rates generated a reduction in consumption between 1.6% and 3.1%, while CPP rates caused much more significant falls, of between 10.2% and 16.1%. In summary, although critical-peak pricing achieves larger reductions in consumption, the relationship between consumption reduction and price increase is more pronounced in time-of-use tariffs.

In a recent study, Bollinger and Hartmann (2020) found that consumers did not respond significantly to the introduction of dynamic pricing. The authors argued that these results were due to the lack of technologies providing information on consumption and prices or, even, to the impossibility of adjusting consumption automatically. To delve deeper into the role that technologies can play in enhancing the effectiveness of dynamic pricing, the following section analyses how their implementation can facilitate the flexibility of electricity demand.

6.4. **Technologies for improving the effectiveness of dynamic pricing**

As we saw in the previous section, the introduction of dynamic pricing does not always trigger changes in electricity consumption. Among the possible reasons for this are the lack of information that households possess regarding their total energy consumption, the marginal consumption of each household appliance, and the price paid at any given time to consume energy according to their tariff. As seen above, energy reports can help to close this information gap, but for this to happen the information must be provided at frequent intervals. An alternative to energy reports is provided by technologies that offer real-time information on electricity consumption and price, mainly in the form of in-home display energy monitors.

A second reason that may discourage households from modifying their behaviour, even if they have all the information they need, is the cost of adjusting their consumption. In this case, technologies capable of automating household response, such as programmable communicating thermostats,[11] may be essential to maximize the effects of dynamic pricing and of other interventions aimed at improving household energy consumption patterns.

This section presents the results of studies that have analysed the effects of introducing these technologies in contexts where households face dynamic pricing tariffs.

6.4.1. Do energy monitors improve the effectiveness of dynamic pricing?

Five studies have been identified that evaluate the effects of introducing energy monitors in households with dynamic pricing tariffs (Table 7).

Table 7. Additional effects of the adoption of energy monitors

Study	Country	Intervention	Type of pricing	Variable	Result
Bollinger & Hartmann (2020)	Oklahoma (United States)	Energy monitor	TOU	Electricity consumption	-8.8%
			CPP		No significant effects
Harding & Lamarche (2016)	United States	Energy monitor	TOU	Electricity consumption	Peak hours: 0% / -15% Off-peak hours: 0%
Jessoe & Rapson (2014)	Connectitut (United States)	Energy monitor + warning 24h before	CPP	Electricity consumption	-17%
		Energy monitor + warning 30 mins before			No significant effects

[11] Thermostats can be seen as investments aimed at improving energy efficiency: if the energy service is to maintain the house at a certain temperature, the thermostat optimizes it while reducing energy consumption. They have been included in this review due to their interaction with dynamic pricing and their contribution to changing household habits.

Martin & Rivers (2018)	Ontario (Canada)	Energy monitor	TOU	Electricity consumption	-3.4%
Prest (2018)	Ireland	Energy monitor	TOU	Electricity consumption	-14.6%

On the one hand, four studies analysed the effects of installing **monitors in households with TOU tariffs**, and concluded that they can increase the effectiveness of the tariff. Prest (2018) estimated that the introduction of a monitor obtained an additional 5.6% reduction in consumption, in addition to the 9% achieved by the TOU tariff itself. Bollinger and Hartmann (2020) also find that, unlike households without a monitor, where no significant reductions were detected, those with a monitor reduced consumption by 8.8%. Harding and Lamarche (2016) found that having a monitor did not induce significant changes in consumption in households with time-based tariffs compared to households with the same tariff but which could also consult a website containing information on prices and consumption. Finally, Martin and Rivers (2018) reported that the introduction of a monitor led to an average reduction in consumption of 3.4%, although they did not establish that this reduction was greater during peak hours; thus it would appear that the monitors do not trigger a specific price-response behaviour, but a more generalized behavioural change motivated by greater awareness of consumption. This interpretation is reinforced by the fact that the reduction increased progressively as the weeks passed after the adoption of the monitor, presumably due to a change in consumption habits.

Two studies analysed the introduction of **energy monitors in contexts with CPP rates**. Bollinger and Hartmann (2020) reported that the device did not lead to a significant reduction in consumption. Jessoe and Rapson (2014) compared three groups of households: (1) households without an energy monitor, (2) households with a monitor notified 30 minutes before the peak event, and (3) households with a monitor notified 24 hours in advance of the peak event. In the first two cases, the authors don't find a significant reduction, indicating that, if the warning was issued only 30 minutes beforehand the presence of the monitor does not provide any additional effect; in the third group, however, the monitor did have a notable impact, achieving a reduction in consumption of 17%.

These results lead to an important conclusion: for monitors to be effective, households must have time to adjust their consumption. In contexts with CPP rates, this anticipatory capacity can be achieved through warnings made with a certain margin of time, as is the case with TOU tariffs under which households know in advance the periods in which peak rates will apply. Therefore, for the technology to be effective, consumers must be informed of price changes with sufficient advance notice.

6.4.2. Do thermostats improve the effectiveness of dynamic pricing?

A second group of studies (eight in total) analysed the effect of combining thermostats with dynamic price tariffs (Table 8Table).

Table 8. Additional effects of the adoption of thermostats

Study	Country	Intervention	Technology	Variable	Result
Blonz et al. (2023)	Ontario (Canada)	Thermostat + algorithm	TOU	Air conditioning operating time	-88% in peak periods
				Thermal discomfort (deviation from optimal temperature)	0.3° F of the set (preferred) temperature
Bollinger & Hartmann (2020)	Oklahoma (United States)	Thermostat	TOU	Electricity consumption	-21.5%
			CPP		-29.3%
Faruqui & George (2005)	California (United States)	Thermostat	TOU	Electricity consumption	-27%
Faruqui et al. (2012)	Connecticut (United States)	Thermostat	TOU	Electricity consumption	-1.6% / -3.1%
			CPP		-15.1% / -23.3%
Faruqui et al. (2013)	Michigan (United States)	Thermostat	CPP	Electricity consumption	-19.4%
Gillan (2017)	California (United States)	Thermostat	CPP (+30%)	Electricity consumption	-60%
			CPP (+1875%)		
Harding & Lamarche (2016)	United States	Thermostat	TOU	Electricity consumption	Peak hours: -10% / -48% Off-peak hours: 0% / + 22%
Wolak (2010)	District of Columbia (United States)	Thermostat	CPP	Electricity consumption	-20%

Studies that have analysed the installation of thermostats in homes with CPP rates have found that this combination can lead to reductions in electricity consumption. Specifically, Bollinger and Hartmann (2020) reported reductions of close to 30%, a figure similar to those found by Faruqui in his various studies. Wolak (2010) found that this combination led to a reduction in consumption of 20%, of which a little more than half can be attributed to the effect of the thermostat. Finally, the largest reductions were reported by Gillan (2017), who recorded figures of 60%, 75% of which was attributable to the thermostat.

Regarding the combination of tariffs with time slots and thermostats, Harding and Lamarche (2016) found significant reductions in consumption of up to 48% during peak hours. Bollinger and Hartmann (2020) and Faruqui et al. (2012) also found that the installation of thermostats influenced energy consumption, although in both cases the effects were smaller than when the use of the thermostat was combined with CPP rates. Finally, Blonz et al. (2023) studied a sample of consumers who initially already had a TOU tariff and a thermostat. Part of the sample was offered the option of implementing an algorithm that allowed pre-cooling the home when prices were low and stopping the air conditioning when prices rose, as long as the temperature did not exceed a certain level. The main results were as follows: households with the possibility of implementing the algorithm set a higher default temperature and reduced the operating time of the air conditioning, without this affecting their comfort in the home; at the same time they managed to save by shifting their air conditioning consumption to hours with low rates. These results highlight the key role of the way in which households interact with thermostats.

Taken together, these results show that problems of information and action costs are indeed barriers that make it difficult for household electricity demand to respond to price changes. However, as has been seen, the provision of information via energy monitors for users in TOU systems can help them to acquire new habits and reduce their consumption. With CPP systems, it seems that even when access to information is easily available via an energy monitor, action costs remain a significant obstacle that discourages users from reacting to price changes. In these cases, the most important gains are determined by automation thanks to thermostats (Bollinger and Hartmann 2016).

Thus, the adoption of technologies can help to make demand more flexible. However, as detailed in the previous synthesis, “What works to improve the energy efficiency of buildings? Policies and programmes to incentivize the adoption and use of efficient technologies” (Enrich, 2025), barriers to the adoption of these technologies in households may persist. In this context the study by Gillan (2017) is important, since it assesses whether subsidies can incentivize the adoption of thermostats. The results of that study indicate that a subsidy of around $200 increases the proportion of households that will install a thermostat, the difference being particularly marked in households with lower consumption. These findings suggest that the initial investment costs may constitute a significant barrier to the adoption of these technologies, especially among the more vulnerable segments of the population.

7. Conclusions

Improving household energy habits and promoting changes in consumption patterns are necessary conditions for reducing GHG emissions in the residential sector. In addition, as renewables gain prominence in the energy mix, policies aimed at making demand more flexible and shifting it to periods with a greater presence of renewables can also bring down electricity bills without reducing energy services. This article presents a review of the existing literature on programmes designed to incentivize a reduction in consumption, mainly electricity, or to shift it to times when production costs are lower and the carbon footprint is smaller.

In relation to public policy instruments, three types of intervention have been analysed. The first comprise information programmes that help to make households more aware of the energy services they use, their consumption and the associated expenses, and ways to save energy. Second, economic incentives in the form of subsidies have been evaluated, followed by interventions based on the design of dynamic pricing tariffs. Finally, we have explored how the adoption of new technologies can help reduce the costs both of obtaining information and of reacting to price changes in contexts where these tariffs has been implemented.

The evidence reviewed suggests that the effectiveness of the different instruments varies significantly depending on the characteristics of the target population, the design of the programme, and the technology adopted. However, certain common characteristics in the programmes have been identified that must be taken into account when implementing these policies in the in the home. For each conclusion in the list below, a confidence level is included that groups the degree of agreement between the studies analysed and the robustness of the results obtained.

The main conclusions regarding information interventions are as follows:

- Energy consumption reports can be an effective, low-cost and relatively uncontroversial alternative to price-based instruments such as taxes, although they achieve only moderate reductions in consumption (confidence level = high).
- In order to induce changes in habits and to ensure that they endure over time, the reports must be issued frequently and over extended periods (confidence level = medium).
- The effects are greater in households in which initial consumption is above average. This is due to the greater room for manoeuvre that these households possess and the influence of perceived social norms regarding peer comparison (confidence level = high).
- Energy consumption reports may have counterproductive effects in households whose previous consumption was below average or who had underestimated it; in this case they may opt to increase it, in a phenomenon known as the boomerang effect (confidence level = medium).
- Including messages indicating approval or disapproval of consumption in the reports can increase their effectiveness, and help contain the boomerang effect (confidence level = medium).

- In-person audits that include tips on energy saving are potentially a more effective alternative to periodical reports, although they are also less cost-effective (confidence level = medium).

Regarding the use of subsidies to reduce energy consumption, the main conclusions are as follows:

- Conditional subsidies can be an effective tool in encouraging households to reduce their energy consumption (confidence level = high)
- Subsidies are most effective in low-income households and in areas with more extreme temperatures (confidence level = medium)
- Combining economic incentives with social comparison strategies may reduce their effectiveness (confidence level = medium).

The main conclusions regarding the introduction of dynamic pricing in order to alter consumption patterns are:

- Both CPP and TOU tariffs have the potential to significantly reduce consumption during peak hours (confidence level = high).
- In general, this consumption does not shift to lower-price hours, so total consumption falls (confidence level = medium).
- In order to maximize the effectiveness of peak tariffs, households need to be warned of price increases well in advance (confidence level = high).
- TOU tariffs are better suited to promoting long-term behaviour change (confidence level = high).
- Dynamic pricing may disadvantage lower-income households which have less room for manoeuvre; however, the evidence is inconclusive (confidence level = low).

Regarding the use of technologies to encourage demand response:

- Energy monitors are useful for addressing information issues and for promoting long-term reductions in consumption through changes in behaviour (confidence level = high).
- These monitors work better as a complement to TOU tariffs than to CPP tariffs (confidence level = medium).
- Adjustable thermostats facilitate household energy savings and are more effective than monitors in reducing short-term consumption, making them an excellent complement to critical-peak pricing. (confidence level = high).

8. Discussion and practical implications

The transition to a carbon-free economy requires a rapid and robust expansion of renewable energy. With wind and solar power playing a central role, measures are needed to adapt to their intermittent nature, either by shifting consumption or reducing it when these sources are not available. Only then can their full potential be harnessed, ensuring clean and affordable energy.

The conclusions of this synthesis can help to transform consumption habits in the residential sector by encouraging energy savings and increasing the flexibility of demand. This section contextualizes the results inside the current framework and offers a set of recommendations for implementing these interventions in Catalonia.

With regard to **energy consumption reports**, since 2021, energy suppliers have been subject to specific regulations that determine the information they must provide alongside the bill.[12] Among other things, they must provide information on average hourly consumption, accumulated consumption and maximum power used. They must inform consumers that they may consult their hourly consumption on the website of the distribution company. Bills usually include advice on energy saving, although it does not tend to be very specific. On the other hand, there is no legal obligation on the part of energy suppliers to provide a comparison between the energy consumption of a household and that of other similar households. These limitations mean that there is scope for improving the accessibility and usefulness of the information provided.

To complement the information provided by energy suppliers, one public policy option is to encourage **energy audits** to provide households with detailed knowledge of their energy consumption and its origin, thus enabling them to identify saving measures.

The fact that almost all households in Catalonia currently have a smart meter installed makes it easier to adopt complementary technologies that provide consumers with real-time information on their energy consumption, such as energy monitors. In this regard, a more scalable alternative would be to offer households subsidies for installing energy monitors, or make their installation compulsory, following the example of the smart meter requirement established a few years ago. In the case of smart meters, the cost usually falls on consumers through a monthly rental fee, even though the main beneficiaries of their installation are the energy distributors, since they obtain real-time information about household consumption. Complementing these meters with energy monitors for domestic use would ensure that this information also reaches consumers.

The second block of this synthesis analysed the effectiveness of **dynamic pricing programmes** for improving demand flexibility. The evidence reviewed has shown that these tariffs are able to reduce electricity consumption during hours when prices are high. However, it is seen that

[12] https://www.boe.es/buscar/act.php?id=BOE-A-2021-7120

consumers are not usually sensitive to the magnitude of price changes, and that not all consumers have the same ability to adapt; specifically, households with lower incomes often find it more difficult to reduce their consumption during the most expensive and polluting times of day. This inequality can be exacerbated by the introduction of technologies such as electric vehicles, which offer many options for adjusting and programming their electricity consumption but are mostly adopted by households with high incomes. For this reason, it is essential to investigate the distributional effects of dynamic tariffs to make sure that they do not disproportionately harm the most vulnerable groups. Although the literature in this area offers mixed results, we can extract a series of recommendations.

In order to design dynamic pricing systems that minimize unwanted distributional effects, it is essential to understand the consumption habits of different segments of the population. Cahana et al. (2023) analysed the distributional effects of the introduction of dynamic pricing in Spain in 2015 and concluded that they were regressive, but had a limited economic impact. This regressiveness is mainly due to the combination of two factors: first, the fact that price differences between seasons are greater than hourly variations within the same day; second, the fact that households with higher incomes tend to consume disproportionately more during peak hours of the day, while households with lower incomes consume relatively more during the winter months. Leslie et al. (2024) found that lower-income households are more likely to have inefficient electric heaters, a circumstance that significantly increases their bills during the winter months when prices are higher, while higher-income households tend to have air conditioning systems whose consumption is concentrated during the summer months.

In the same study, Leslie et al. (2024) also observed that lower-income households consume relatively more during hours of sunlight than their higher-income peers, given the type of energy services they use. For example, as already mentioned, higher-income households are more likely to have high consumption during electric vehicle charging hours, which are currently concentrated at night. This implies that in settings where solar energy is a significant component of the energy supply (and is cheaper and causes less pollution during the day) the use of fixed price systems will mean that the most vulnerable households are implicitly subsidizing the consumption of higher-income households. This effect will become more pronounced as we advance in the energy transition and solar production takes on a greater role.

In Catalonia the electricity market is liberalized, which allows companies to offer their own tariffs. However, a series of commercial groups also act as electricity distributors, so they can offer the regulated tariff which, since 2015, has followed wholesale market prices. This tariff is adopted to a greater extent by households with lower incomes, partly because doing so is a necessary condition to be able to apply for a rebate known in Spain as the *Bono Social*, a government programme that gives electricity discounts to vulnerable households. Taking this into account, and especially since many low-income households do not have their own solar production, a first measure that could be taken would be to maintain the daily variations in this tariff but compensate for the differences in prices between different seasons of the year.

Another aspect that should be reviewed is the distribution of the time slots applied to the regulated part of the tariff. Currently, peak hours include not only the evening, when electricity production is more expensive and causes more pollution, but also the central hours of the day. However, the middle part of the day, even though traditionally it has concentrated high demand, is now usually covered by solar energy, with low marginal costs and with no emissions. Therefore, penalizing consumption during these hours no longer has any environmental or economic justification, especially when vulnerable households are known to concentrate a significant part of their consumption in this time of day. So it is necessary to reconsider this time allocation and even incentivize demand in these clean slots.

In parallel, **information and educational measures** should be be implemented to ensure that all users, particularly the most vulnerable groups, have a clear understanding of the tariff. As Prest (2018) points out, the most decisive factor for the effectiveness of hourly tariffs is that consumers should know how they work. Without this knowledge, even a well-designed pricing structure will have only a limited impact.

In fact, the study by Fabra et al. (2021), focused on the large-scale implementation of dynamic pricing in Spain since October 2015, exemplifies the critical importance of ensuring that users are aware of and understand how the tariff works. Although the regulated real-time pricing (RTP) tariff set variable hourly prices with an average difference of 23% between the maximum and minimum, and this information was published a day in advance, no significant response in household consumption was observed. The authors largely attribute this result to consumers' lack of knowledge and awareness of the existence and characteristics of the tariff—a prerequisite for time-of-use tariffs to be effective. Furthermore, the low price variability during the period and the high information and monitoring costs for consumers limited their ability to respond. It should be noted that this study analyses a period prior to the 2022 energy crisis, so it is plausible that the recent increase in volatility and prices has heightened incentives and consumers' willingness to adjust their consumption.

Finally, these reflections should be contextualised within the current energy framework. First, the technology exists for the residential sector to participate in electricity market flexibility mechanisms. Indeed, the 2019 European Directive[13] already encourages demand response through aggregators that group different household loads and offer them to the market. Nevertheless, the level of transposition into Spanish regulation remains low. This coordination, facilitated by the use of adjustable thermostats, could have a multiplier effect on the policies described in this synthesis.

Moreover, although this synthesis has reviewed policies aimed at flexibilising electricity demand and reducing energy consumption, it should not be forgotten that, if the goal is to reduce greenhouse gas emissions, aggregate demand for electricity generated from renewable

[13] Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity.

sources must also increase. Progressing in this direction requires rethinking the overall approach to energy consumption. In this regard, achieving a perfect time-of-use tariff design may not be necessary; rather, the focus should be on promoting the competitiveness of electricity relative to direct gas consumption (e.g., by encouraging the installation of heat pumps) or oil (e.g., by promoting the adoption of electric vehicles). Additionally, with the dramatic fall in prices experienced by electricity storage systems—mainly batteries—demand flexibilisation would become secondary, prioritising the electrification of domestic energy uses.

In conclusion, an increase in electricity consumption can be positive if it substitutes for more polluting energy sources and as long as rebound effects are limited. Therefore, policies aimed at improving efficiency and equity in electricity consumption should be accompanied by fiscal measures that penalise high-emission energy sources. In this way, a just and efficient energy transition could be ensured.

9. References

Allcott, H. (2011a). Rethinking real-time electricity pricing. Resource and Energy Economics, 33(4), 820–842. https://doi.org/10.1016/j.reseneeco.2011.06.003

Allcott, H. (2011b). Social norms and energy conservation. Journal of Public Economics, 95(9–10), 1082–1095. https://doi.org/10.1016/j.jpubeco.2011.03.003

Allcott, H., & Rogers, T. (2014). The short-run and long-run effects of behavioral interventions: Experimental evidence from energy conservation. In American Economic Review (Vol. 104, Issue 10, pp. 3003–3037). American Economic Association. https://doi.org/10.1257/aer.104.10.3003

Asensio, O. I., & Delmas, M. A. (2015). Nonprice incentives and energy conservation. Proceedings of the National Academy of Sciences of the United States of America, 112(6), E510–E515. https://doi.org/10.1073/pnas.1401880112

Blonz, J., Palmer, K., Wichman, C. J., & Wietelman, D. C. (2023). Smart Thermostats, Automation, and Time-Varying Prices.

Boiteux, M. (1960). Peak-Load Pricing. In Source: The Journal of Business (Vol. 33, Issue 2). https://www.jstor.org/stable/2351015

Bollinger, B. K., & Hartmann, W. R. (2020). Information vs. Automation and implications for dynamic pricing. Management Science, 66(1), 290–314. https://doi.org/10.1287/mnsc.2018.3225

Burkhardt, J., Gillingham, K. T., & Kopalle, P. K. (2023). c Management Science, 69(12), 7784–7798. https://doi.org/10.1287/mnsc.2020.02074

Byrne, D. P., Nauze, A. La, & Martin, L. A. (2017). Tell Me Something I Don't Already Know: Informedness and the Impact of Information Programmes. https://ssrn.com/abstract=2430135

Cahana, M., Fabra, N., Reguant, M., & Wang, J. (2023). The Distributional Impacts of Real-Time Pricing. https://www.energypoverty.eu/

Costa, D. L., & Kahn, M. E. (2013). Energy conservation "nudges" and environmentalist ideology: Evidence from a randomized residential electricity field experiment. Journal of the European Economic Association, 11(3), 680–702. https://doi.org/10.1111/jeea.12011

Dolan, P., & Metcalfe, R. (2015). Neighbors, knowledge, and nuggets: Two natural field experiments on the role of incentives on energy conservation. https://ssrn.com/abstract=2589269

Enrich, J., Li, R., Mizrahi, A., & Reguant, M. (2024). Measuring the impact of time-of-use pricing on electricity consumption: Evidence from Spain. Journal of Environmental Economics and Management, 123. https://doi.org/10.1016/j.jeem.2023.102901

Enrich, J. (2025). What works to improve the energy efficiency of buildings? Policies and programmes for encouraging the adoption and use of efficient technologies. Barcelona: Ivàlua.

Fabra, N., Rapson, D., Reguant, M., & Wang, J. (2021). Estimating the Elasticity to Real-Time Pricing: Evidence from the Spanish Electricity Market. AEA Papers and Proceedings, 111, 425–429. https://doi.org/10.1257/pandp.20211007

Faruqui, A., & George, S. (2005). Quantifying customer response to dynamic pricing. Electricity Journal, 18(4), 53–63. https://doi.org/10.1016/j.tej.2005.04.005

Faruqui, A., & Sergici, S. (2011). Dynamic pricing of electricity in the mid-Atlantic region: Econometric results from the Baltimore gas and electric company experiment. Journal of Regulatory Economics, 40(1), 82–109. https://doi.org/10.1007/s11149-011-9152-5

Faruqui, A., Sergici, S., & Akaba, L. (2012). Dynamic Pricing in a Moderate Climate: The Evidence from Connecticut. http://ssrn.com/abstract=2028178

Faruqui, A., Sergici, S., & Akaba, L. (2013). Dynamic pricing of electricity for residential customers: The evidence from Michigan. Energy Efficiency, 6(3), 571–584. https://doi.org/10.1007/s12053-013-9192-z

Fowlie, M., Wolfram, C., Baylis, P., Spurlock, C. A., Todd-Blick, A., & Cappers, P. (2021). Fowlie et al. (2021), Review of Economic Studies, 88(6), 2886–2934. https://doi.org/10.1093/restud/rdab018

Garnache, C., Hernaes, Ø., & Imenes, A. G. (2022). Which Households Respond to Electricity Peak Pricing Amid High Levels of Electrification? (9657).

George, S. S., & Bell, E. (2018). Key findings from California's recent statewide TOU pricing pilots. Electricity Journal, 31(8), 52–56. https://doi.org/10.1016/j.tej.2018.09.013

Gillan, J. (2017). Dynamic Pricing, Attention, and Automation: Evidence from a Field Experiment in Electricity Consumption.

Harding, M., & Lamarche, C. (2016). Empowering Consumers Through Data and Smart Technology: Experimental Evidence on the Consequences of Time-of-Use Electricity Pricing Policies. Journal of Policy Analysis and Management, 35(4), 906–931. https://doi.org/10.1002/pam.21928

Harding, M., & Sexton, S. (2017). Household Response to Time-Varying Electricity Prices. https://doi.org/10.1146/annurev-resource

Hofmann, M., & Lindberg, K. B. (2024). Evidence of households' demand flexibility in response to variable hourly electricity prices – Results from a comprehensive field experiment in Norway. Energy Policy, 184. https://doi.org/10.1016/j.enpol.2023.113821

Institut Català de l'Energia. (2022). Balanç energètic de Catalunya. Https://Icaen.Gencat.Cat/ca/Energia/Estadistiques/Resultats/Anuals/Balanc_energetic/.

Ito, K. (2015). Asymmetric incentives in subsidies: Evidence from a large-scale electricity rebate programme. American Economic Journal: Economic Policy, 7(3), 209–237. https://doi.org/10.1257/pol.20130397

Ito, K., Ida, T., & Tanaka, M. (2018). Moral Suasion and economic incentives: Field experimental evidence from energy demand. American Economic Journal: Economic Policy, 10(1), 240–267. https://doi.org/10.1257/pol.20160093

Jessoe, K., Lade, G. E., Loge, F., Spang, E., Davis, L., Ferraro, P., Fowlie, M., Heutel, G., Olmos, K., Novan, K., Price, M., Rudik, I., Smith, A., & Wichman, C. (2017). Spillovers from Behavioral Interventions: Experimental Evidence from Water and Energy Use 1. https://www.economist.com/news/international/

Jessoe, K., & Rapson, D. (2014). Knowledge is (Less) power: Experimental evidence from residential energy use. American Economic Review, 104(4), 1417–1438. https://doi.org/10.1257/aer.104.4.1417

Joskow, P. L., & Wolfram, C. D. (2012). Dynamic pricing of electricity. American Economic Review, 102(3), 381–385. https://doi.org/10.1257/aer.102.3.381

Khanna, T. M., Baiocchi, G., Callaghan, M., Creutzig, F., Guias, H., Haddaway, N. R., Hirth, L., Javaid, A., Koch, N., Laukemper, S., Löschel, A., Zamora Dominguez, M. del M., & Minx, J. C. (2021). A multi-country meta-analysis on the role of behavioural change in reducing energy

Què funciona contra el canvi climàtic?

consumption and CO2 emissions in residential buildings. Nature Energy, 6(9), 925–932. https://doi.org/10.1038/s41560-021-00866-x

Leslie, G. W., Pourkhanali, A., & Roger, G. (2024). Is the clean energy transition making fixed-rate electricity tariffs regressive? Journal of Environmental Economics and Management, 127. https://doi.org/10.1016/j.jeem.2024.103040

Martin, S., & Rivers, N. (2018). Information provision, market incentives, and household electricity consumption: Evidence from a large-scale field trial. Journal of the Association of Environmental and Resource Economists, 5(1).

Ministeri d'Inclusió, Seguretat Social i Migracions. (2024). Proyecto de Formación y Mejoras en Viviendas para el Abordaje de la Pobreza Energética. Laboratorio de Políticas de Inclusión.

Pellerano, J.A., Price, M.K., Puller, S.L. & Sánchez, G.E. (2017). Do Extrinsic Incentives Undermine Social Norms? Evidence from a Field Experiment in Energy Conservation. Environmental and Resource Economics, 413-428, 67(3)

Prest, B. C. (2018). Peaking Interest: How Awareness Drives the Effectiveness of Time-of-Use Electricity Pricing. 7(1). https://doi.org/10.7910/DVN/CNQUN3

Proyecto de Formación y Mejoras en Viviendas para el Abordaje de la Pobreza Energética. (2024). Laboratorio de Políticas de Inclusión.

Schultz, P. W., Nolan, J. M., Cialdini, R. B., Goldstein, N. J., & Griskevicius, V. (2007). The Constructive, Destructive, and Reconstructive Power of Social Norms.

Suter, J. F., & Shammin, M. R. (2013). Returns to residential energy efficiency and conservation measures: A field experiment. Energy Policy, 59, 551–561. https://doi.org/10.1016/j.enpol.2013.04.003

Wolak, F. A. (2010). An Experimental Comparison of Critical Peak and Hourly Pricing: The PowerCentsDC Programme. http://www.stanford.edu/group/fwolak/cgi-bin/sites/default/files/files/An%20Experimental%20Comparison%20of%20Critical%20Peak%20and%20Hourly%20Pricing_March%202010_Wolak.pdf

Què funciona contra el canvi climàtic?

Què funciona contra el canvi climàtic?

Evidence synthesis and knowledge transfer project to improve climate change mitigation and adaptation policies.

A project by:

ivàlua Institut Català d'Avaluació de Polítiques Públiques

COAMB Col·legi d'Ambientòlegs de Catalunya

Generalitat de Catalunya

Què funciona?