Solar rebound: does PV help decarbonize the house ?*

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March 2, 2026

Abstract

In recent years, many households have invested in solar photovoltaics panels and have become prosumers. It is now well documented they tend to increase electricity consumption after panel installation, a classical case of the "rebound effect". Yet, little is known about the drivers of this increase in power consumption. Do solar households buy new power-hungry appliances or do they substitute other energy sources (gas, fuel oil) for electricity. We give a preliminary answer by studying the gas–electricity substitution as prosumers may stop using natural gas for cooking, domestic hot water or heating, employing instead an induction cooktop, a microwave oven, a kettle or electric radiators. If so, we should observe a decrease of their natural gas consumption.

To test this hypothesis, we employ the consumption data provided by RESA, the major distribution system operator (DSO) for the Liège area in Wallonia, Belgium. We select the over 12,000 clients who have installed solar PV and are connected to the natural gas network. We propose different panel data estimation strategies of the solar rebound and we identify a negative impact of being prosumer on the natural gas consumption, which decrease by 3.5% after the installations of the panels.

Keywords: Rebound effect; Solar PV; Net metering; Clean Transition; Natural Gas

JEL Codes: C51, Q48, Q58, Q410, Q420

*incomplete draft, DO NOT CITE

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1 Introduction

Solar photovoltaic (PV) is arguably the *energy transition* flag bearer but with a limited share in the electricity mix, and an even smaller one in the energy mix, plenty of space remains to keep developing this renewable alternative to fossil fuels. Moved by a mix of ecological conscience, peer pressure and governmental incentives, numerous households have invested into rooftop PV panels, thus raising further awareness on energy issues and actively contributing to the transition when becoming *prosumers*.

However, there are growing evidence of a *solar rebound* effect: After they have installed solar panels, prosumers change their habits and they increase their electricity consumption. This solar rebound is driven by both an income effect and a substitution effect, as the relative price of electricity may change. The relative importance of these two effects and therefore the magnitude of the solar rebound depends on the policy context (cf. (Oliver *et al.*, 2024) and (Boccard and Gautier, 2021). Several studies have documented that prosumers increase their electricity consumption, sometimes by more than 20% (main references).

Despite these numerous pieces of evidence, little is known about the drivers of this increase in electricity consumption. On one hand, prosumers may invest in power-intensive appliances and use more electricity to enhance their comfort at home, for instance by purchasing a larger refrigerator, installing air conditioning in every room, adding a jacuzzi, or expanding outdoor lighting. On the other hand, they may substitute other energy sources with electricity. For example, they may acquire and charge an electric vehicle (EV), thereby reducing their gasoline consumption, or install electric radiators to limit their use of fuel oil or natural gas for space heating.

In the first case, the observed solar rebound should leave the consumption of other fuels unchanged and lead to a net increase in the household's overall energy use. In the second case, the positive electricity rebound would be associated with reduced consumption of alternative energy sources and, potentially, a decrease in total household energy consumption. In this paper, we intend to test empirically this hypothesis.

Our analysis concentrates on electricity–gas substitution, as households face several opportunities to replace natural gas with electricity. Prosumers may discontinue the use of natural gas for cooking, domestic hot water, or space heating, switching instead to electric alternatives such as induction cooktops, microwave ovens, kettles, electric radiators, boiler(?) or heat pumps. The latter option typically requires additional investments in home insulation to operate efficiently.

For that task, we use the consumption data provided by RESA, the major *distribution system operator* (DSO) for the Liège area in the Walloon region of Belgium in charge of distributing electricity and natural gas. Boosted by generous subsidies, many households have invested in a solar installation. We focus on the about 12 000 clients who have installed solar PV and also hold a connection to the natural gas network in 34 municipalities. The data cover a large period as we can track consumption for some clients up to 2007. We study the change in their consumption for both energy fuels after the installation of their PV system.

The institutional context of Wallonia/Belgium for prosumers is particularly amenable to our analysis as it combines net metering, a volumetric tariff and a yearly billing. These characteristics allow prosumers to consume their solar energy at will over the yearly billing period without any need to synchronize power consumption with PV generation. One may basically produce during summer and consume during winter. Net metering combined with yearly billing thus considerably facilitates the substitution of natural gas by electricity. It makes swapping power for natural gas most likely, although it might require the acquisition of new appliances. Accordingly, we should observe a positive solar rebound for electricity but a negative one for gas. We intend to test if it is indeed the case.

This is an important policy question because prosumers are on average, wealthier, better educated and more aware of environmental issues, thus should be more prone to save energy, reduce their electricity consumption and swap natural gas for electricity. However, the legislative attempts in California and Germany to forcefully replace natural gas with electricity have created a backlash because proponents did not consider the consumers' behavior in sufficient detail. It is therefore crucial to understand whether there are "natural" incentives to switch.

The complete draft will include the statistical methodology and a summary of the results.

This paper is organized as follow. In Section 2, we review the related literature, in Section 4, we briefly present the institutional context for residential PV in Wallonia. In Section 3, we present our data and our sample construction. The main results are displayed in Section 5 and Section 7 concludes.

2 Literature

Absent any solar rebound, households who produce power at home, should not change their electricity consumption, and the solar power would replace electricity from the grid on a one-to-one basis. However, this is not the case as solar households are exposed to an income effect and, under specific conditions, to a substitution effect (Oliver *et al.*, 2024). As solar energy is, in average, cheaper than electricity from the grid, eventually thanks to subsidies, prosumers save on their electricity bill. This additional income can be used for consumption, and, as electricity is a normal good, electricity consumption is likely to increase. Furthermore, prosumers are exposed to a substitution effect as the price of solar power is different from the price of power from the grid. The magnitude of this effect depends on the institutional context in place and, in particular, on the price set for power injection to the grid. There are two main systems for pricing exchanges with the grid, net metering and net billing (Gautier *et al.*, 2018). Under net metering, there is a specific price for power injections. Under net metering, prosumers receive a credit that can be used for future consumption for a given period. If they still have a production surplus at the end of the relevant period i.e. if they produce more than what they consume, this surplus is valued below the retail price and, in some juridictions (as in Wallonia), it is even lost. Therefore, the price for this additional consumption is below the retail price which in turn drives up electricity consumption, a classical substitution effect.

Several papers have documented empirically an increase in electricity consumption by prosumers and there are converging evidence of a significant solar rebound, with an order of magnitude from 10% to 30% increase in electricity consumption. Evidence cover a large set of juridictions: Australia (Deng and Newton, 2017), USA (Qui *et al.*, 2019; Beppler *et al.*, 2021), Belgium (Boccard and Gautier, 2021), Netherlands (Aydin *et al.*, 2023), Swiss (Bigler, 2025), Germany (Frondel *et al.*, 2025; Poier and Bucksteeg, 2025) and Vietnam (Nguyen *et al.*, 2024). Evidences are based either on survey data (Aydin *et al.*, 2023; Poier and Bucksteeg, 2025) or on meter data (Qui *et al.*, 2019; Beppler *et al.*, 2021; Boccard and Gautier, 2021). Note that this solar rebound is intrinsically linked to PV ownership. Cha and Matisoff (2026) do not find a similar rebound for consumers being part of community solar programs where they can buy blocks solar capacity and the associated production in a solar farm nearby their location. The above mentioned studies cover residential consumers. D'Agostia and Danza (2026) identify a rebound effect of similar magnitude (around 20%) for firms in Uruguay.

In Boccard and Gautier (2021), we document a substantial rebound effect for prosumers in Wallonia. We show that the subsidy mechanism in place during the period 2008-2014 encouraged households to oversize their solar installations compared to their consumption needs. With oversized installations, households had free electricity to consume and this drove the rebound effect. This paper uses similar data (but from another DSO) and covers a longer time period and we have, in addition, data on gas consumption to document how becoming a prosumer changes the consumption of both fuel.

As prosumers tend to display specific characteristics; they are home owner, living in detached house, etc. (De Groote *et al.*, 2018), to properly identify the solar rebound effect, many papers use a control group of non-prosumers with similar characteristics, for instance Beppler *et al.* (2021) and Qui *et al.* (2019) and we follow the same approach in this paper.

Despite these converging evidences of a solar rebound, little is known on the drivers of this additional consumption and the underlying behavior change. Using survey data, Keirstead (2007), Wittenberg and Matthies (2016) and Gautier *et al.* (2018) show that prosumers displace their load to better synchronize their consumption with their solar production. Qui *et al.* (2019) has a similar conclusion using meter data. Oberst *et al.* (2018) compare the heating expenditures of german prosumers and non-prosumers and they do not found significant difference in the heating bill of the two groups, once they control for the households characteristics. Accordingly, there is no prosumer effect meaning that prosumers do not subsequently change their (heating) behavior after they installed solar PV. We will focus on a similar question, using the recorded gas consumption of prosumers.

This paper is also related to the literature on household energy consumption. Li and Just (2018) jointly analyze household energy consumption and adoption of energy-efficient technologies, addressing both short-run energy demand (electricity and gas) and long-run appliance choices. A recent OECD survey (OECD, 2024) analyzes household choices regarding energy use and investments in lower-emissions appliances looking at both the households' socio-economic characteristics and the dwelling's physical characteristics. We contribute to this literature by analyzing how the investment in solar PV changes the energy use inside the house, in a context where the switch from gas to electricity may require the use of new appliances.

Finally, add references on fuel substitution in the house TBC.

3 Data source

3.1 Source

Our data come from RESA, the Belgian DSO in charge of electricity and natural gas distribution in the Liège area, covering 74 municipalities (and 295 statistical districts). As shown on Figure 1, RESA distributes both fuels in 38 municipalities, electricity only in 18 where there is no gas network and, in the remaining 18 municipalities, RESA distributes natural gas while power is distributed by another DSO.

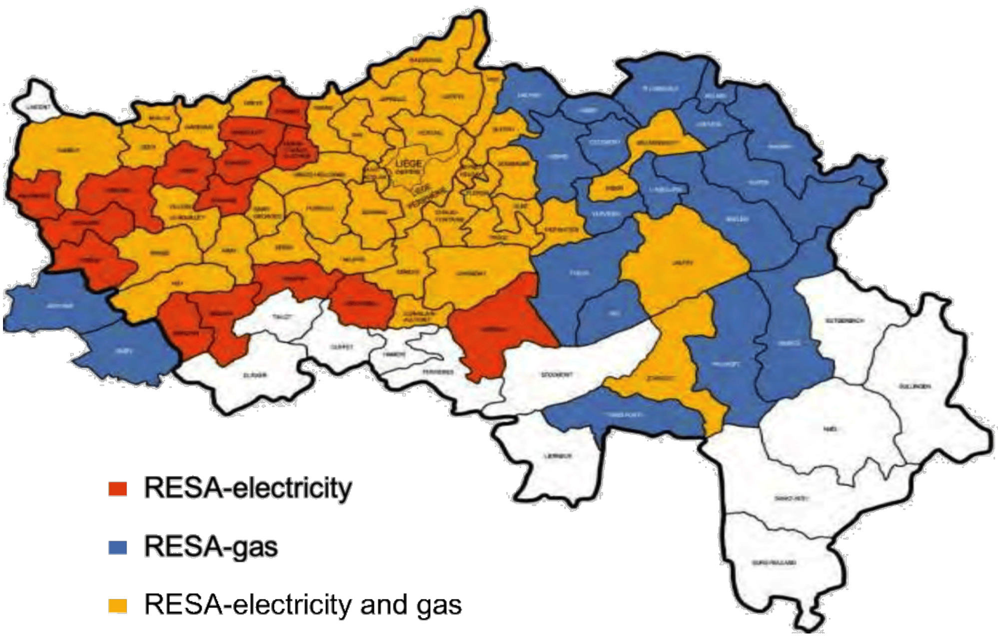

Figure 1: Municipalities covered by RESA

We have a nearly exhaustive dataset from which we can recover the consumption of almost all clients served by RESA. Each client is identified by a unique consumer ID and is associated with up to 2 EAN codes, respectively for natural gas and power accounts; in turn, each EAN couples with one or more meters. For electricity, the most common meters are the single meter and the dual day/night meter while for natural gas, there is always a single meter. Most of the meters are mechanical (as our records go back to 2007) and go back to zero when reaching the maximum value (e.g., 999999). For each meter, we record the date it was read, the meter type and the index value; it is standard praxis to read meters once a year for billing.[1] There are additional meter readings associated with moving in or out, change of ownership, contract or retailer as well as physical alterations such as a new meter or connecting a PV system.

From the meter readings, we reconstruct, for each household i, their consumption (q) of electricity (e) and gas (g) at day d: q^e_{id} and q^g_{id}.[2] Daily measures can be aggregated for month m and year y. Our key inputs are the meter readings and the Synthetic Load Profile (SLP) curves published by Synegrid for each year and each Belgian DSO. These curves give the percentage s of the yearly consumption at each time step (15' for electricity, 60' for gas); properly averaging, we obtain daily measures s^e_d and s^g_d and we use these measures to construct the daily consumptions of gas and electricity. For ease of reading, we express consumptions of electricity and natural gas in *kWh per day* using the DSO calorific rate of 11.31 kWh per cubic meter of gas. We detail the procedure in Appendix A.

Solar PV installations being registered with the DSO, we can gather their connection date, the size (kWp) as well as the inverter power (kVA); the minimum of the two figures then determines the usable power for the prosumer; later modifications are also recorded. In this work, we focus on residential installations (less than 10 kWp) which are eligible for net metering; they form the overwhelming majority of RESA's client base whose composition is detailed in Table 1 for the period 2005-2022.

We select from our almost exhaustive initial dataset all *residential consumers*. We identify residential consumers using the classification provided by RESA, itself based on SLP consumption profiles. During the data treatment phase, we drop clients whose meter is inactive for the entire period of billing or displays uncanny errors. Our sample size is also reduced by the need to observe energy consumption 2 years before and after the PV installation, so that prosumers with the most recent PV connection are dropped.

Fuel (000s)	consumer	prosumer	client
Power	233	38	271
Nat. Gas	78	n.a.	78
Power + Nat. Gas	178	13	191
Total	490	51	541

Table 1: RESA client typology

Although EANs have been anonymized, records still show post code and statistical district (when available); we thus gather socio-economic information at the statistical district level and at the municipality level from public services WalStat and StatBel. Next, we recover electricity and gas retail prices from the Wallon energy regulator (CWAPE) and the wholesale gas price on the European Spot Gas Markets (ZTP). and weather information (temperature and degree days) from the

[1]Within our raw sample, the median duration between two readings is 326 days for power and 342 for gas.

[2]We employ the methodology detailed in Boccard and Gautier (2021).

Meteorological Institute of Belgium (RMI).[3]

4 Solar PV in Wallonia

TBA: paragraphs on current levels of power and gas price as well as the extend of the use of gas.

4.1 Electricity and gas price

In Wallonia, the retail prices for electricity and gas are essentially volumetric (€/kWh and €/m^3) with limited fixed fees and no capacity fees. The retail price includes grid fees and different taxes and surcharges. The energy price charged by the retailer accounts for xx% of the bill for electricity and xx% for gas. Households receive a yearly bill from their retailer based on their meter reading. Retailers offer two types of contract to residential households with fixed or variable prices. The following figure shows the evolution of the power and gas retail prices in the RESA area, based on the figures provided by the regional regulator (CWAPE).[4]

INSERT FIGURE TO BE CONSTRUCTED BASED ON THE DATA PROVIDED BY CWAPE.

Question: do we add statistics on consumption? In the Province of Liège (similar but not equivalent to the area covered by RESA), 42% of the households are connected to the gas network (source IWEPS, https://walstat.iweps.be/walstat-catalogue.php?indicateur_id=813000&ordre=2&periode=31/12/2024&niveau_agre=P&sel_niveau_catalogue=C). Households who are using gas for cooking only have a consumption below 5000 kWh/year, households who are using gas for heating their home have a substantially larger consumption (15 000 -23 000).

4.2 Support to residential PV

In Belgium, the support for renewable energies is delegated to the regions of Flanders, Wallonia & Brussels.[5] Starting in 2008, Wallonia instituted a generous support combining subsides and net metering for residential PV. To be eligible, the PV system had to be installed by a household, usually on its rooftop, with a maximum capacity of 10 kWp.

Subsidies were provided under two different programs, *Solwatt* from 2008 to mid-2014, followed by *Qualiwatt* until July 2018.[6] Since then, no more subsidies were available for new residential PV installations. Under the *Solwatt* program, PV installations received tradable green cer-

[3] Degree days is a proxy for the house heating needs defined as the positive difference between 15°, the temperature at which one should start to heating the house and the external daily average temperature.

[4] The regulator calculates every month a weighted average yearly bill for a representative consumer based on the retail contracts offered on the market. From this average bill, we compute an average retail price per kWh and m^3. Given the tariff structure, this average price is a good proxy for the marginal price faced by the residential consumers.

[5] For detailed information on the subsidy schemes implemented in Belgium, see De Groote *et al.* (2024). They also provide an estimated NPV for a representative installation in the three regions.

[6] Limited investment subsidies and tax cuts were also available until 2012.

tificates (TGC) for each solar MWh produced for a period of 10 to 15 years. The number of TGC received per MWh and the granting period were adapted several times. The *Solwatt* program was excessively generous (Boccard and Gautier, 2021; De Groote *et al.*, 2024), especially during the period 2008-2012, and adoption was massive. In 2014, the *Solwatt* program was replaced by a new subsidy scheme *Qualiwatt*, designed to correct some of the flaws and to reduce the support. The *Qualiwatt* program offered an annual premium, during 5 years, to guarantee the return on investment of a representative installation. The premium was calculated every year, taking into account several parameters, including the energy price. The premium was linked to PV capacity (in kWp) with a cap.

In addition, residential installations benefit from net metering until 2030.[7] With net metering, prosumers receive for each solar MWh that they do not consume, a credit to consume it later, before the end of the billing period, which is usually a year. This feature implies that prosumers have no incentive to synchronize consumption with production (Gautier *et al.*, 2020); at the same time, it can motivate the further electrification of the house.[8]

4.3 Residential PV deployment

Driven by a high return on investment, PV adoption was massive in Wallonia as may be seen on Figure 2 displaying the number of new installations each year in the RESA area. We distinguish between clients with or without connection to the natural gas network. The PV adoption rate fell in 2014 when the *Solwatt* program was terminated. Since then, the number of new installations has been increasing but, as of 2022, has not yet recovered its peak level of 2012. In complementary fashion, Figure 3 shows the evolution of the average installation size. Until 2014, it continuously increased, reflecting both the decline in the cost of the modules and the generosity of the subsidies. At the end of the *Solwatt* program by mid-2014, the average installation size dropped and has remained more or less constant ever since.

Quite clearly, people relying on natural gas for heating or cooking have a lower electricity bill compared to those using electricity only. We find prosumers living in a municipality without natural gas network to consume $\frac{517}{376} - 1 = 37\%$ more electricity (figures in kWh/month). As expected, their PV system size is also $\frac{5.76}{4.68} - 1 = 22\%$ bigger (figures in kWp).

In Boccard and Gautier (2021), we showed the power of incentives whereby the generous production subsidies included within the *Solwatt* program pushed households to build the largest possible PV installations, this because every single PV panel turned out to be an excellent investment. A simple way of checking for the continuation of this behavior in our novel dataset is to

[7]Net metering has been abolished for new installations in 2024.

[8]However, as net metering transfers most of the grid costs to non-prosumers, the regional government decided in 2020 to progressively impose a "prosumer fee" designed to cover the network related cost corresponding to the total consumption from the grid. Households can opt for a fixed fee based on their PV capacity or for one based on their actual withdrawal from the grid. In the latter case, they need a smart meter to record their actual exchanges with the grid.

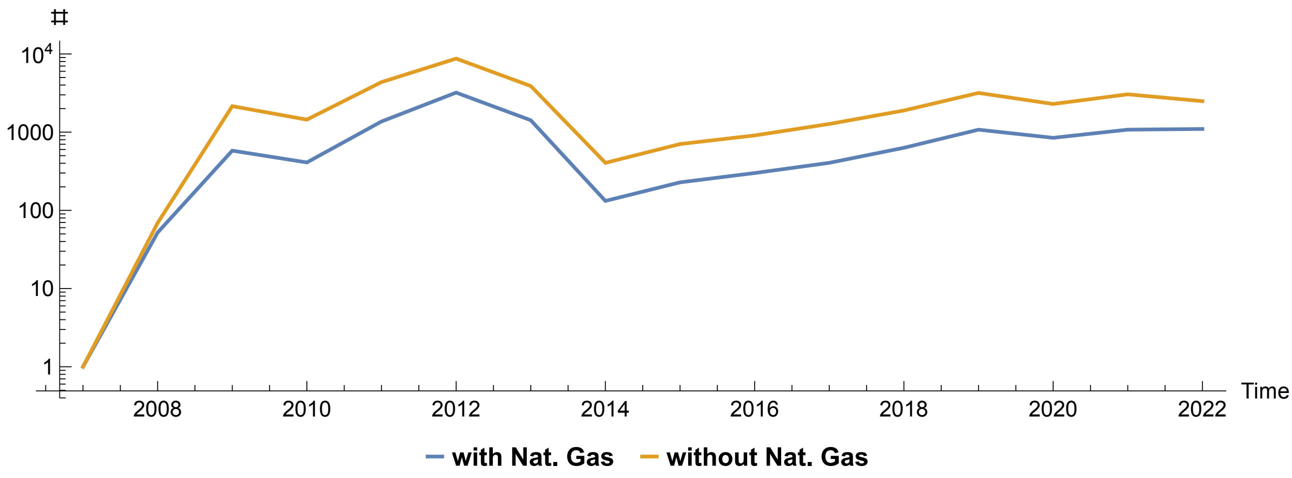

Figure 2: PV installations count

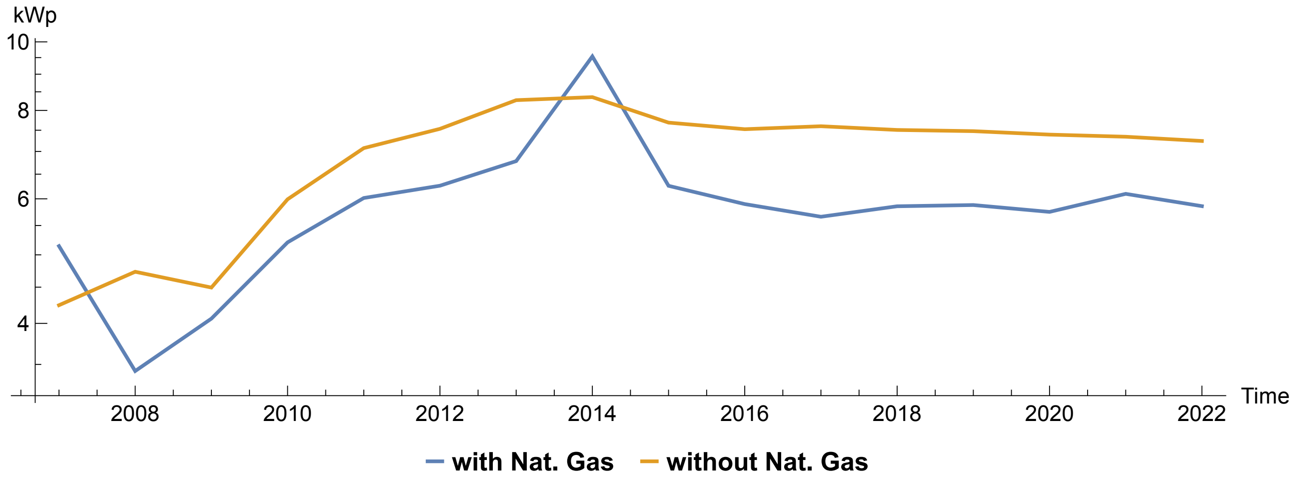

Figure 3: PV installations size

compare the long term yearly output of the PV system to the yearly household consumption over the previous two years; we label an installation *oversized* whenever the former is greater than the latter i.e., $\frac{1}{730}\sum_{\tau-730\leq d\leq\tau} q_d^e < K\bar{\beta}$ where K is the PV size and $\bar{\beta}$ is the long term daily solar output for Liège. All other PV systems are deemed to be *undersized*. Note that *oversized* prosumers tend to consume less than *undersized* ones i.e., live in smaller houses or flats because of the 10 kWp maximum size regulatory constraint. As shown on Figure 4, the *oversized* proportion reached almost 50% at the height of the *Solwatt*-induced craze and as since then fallen back towards 40%.

5 Solar & Natural Gas rebounds

This section starts with some basic tests of whether consumption habits on both inputs were

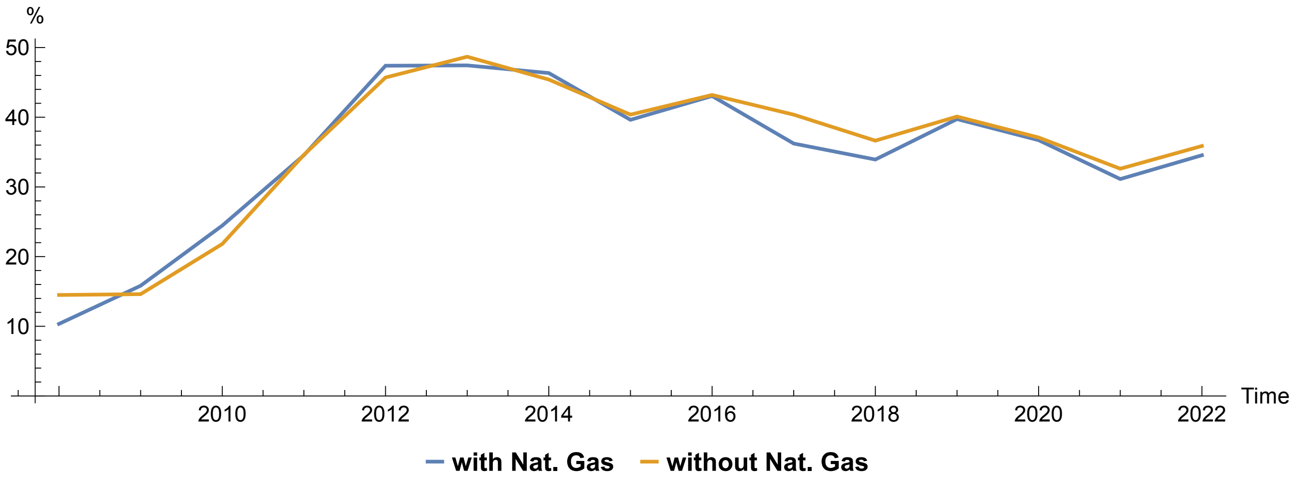

Figure 4: Proportion of *Oversized* PV installations

changed after the PV installation. We then use more advanced strategies to test the preliminary findings. The panel data analysis occupies the next section.

5.1 Basic findings

Does setting-up a PV system impacts the consumption of both power and natural gas ? To provide preliminary answers, we compare for both energy vectors the average consumption 2 years before and 2 years after the PV installation. However, we must firstly eliminate any background trend; this can only be performed over a "placebo" dataset of similar consumers. Yet, as prosumers tend to display specific characteristics (e.g., own a detached house, well-off), we must adequately subsample the large dataset of consumers. For that task, we compute in each statistical sector the ratio of prosumers to consumers which is very low in central Liège where high-rise buildings dominate but large in bourgeois villages. Using these weights, we sample consumers to create the placebo dataset over which we can compute consumption trends for power and gas;[9] we find power load to fall at 75 basis points (bp) per year while natural gas consumption grows by a smallish 8 bp. Regarding total energy, since the power load is about a quarter of the natural gas consumption, the rate of change is −6 bp. Hence, when comparing mean power load from "2 years before" with "2 years after", we should discount the variation by 150 bp (1.5%). For natural gas and total energy, there is almost no discount to apply.

Going back to the prosumer dataset, we can now compute the "before" and "after" average daily consumption $q_b = \sum_{0<\tau-d\leq 720} q_d$ and $q_a = \sum_{0<d-\tau\leq 720} q_d$.

[9] The sampling exercise is repeated a few times to make sure the findings are robust.

Electricity Let us start with electricity consumption. Table 2 displays our preliminary evidence looking at the extreme quartiles and the median (of the "before" power load distribution).[10]

We observe with the median household of the full sample that average consumption increases after the installation of rooftop PV panels (+11% , compared to a trend of -1.5% for non prosumers) but the evolution differs radically between the two groups; in the *undersized* one, it is essentially stable although increasing for people who had a prior low consumption and falling for those who add an elevated load. The situation is quite different in the *oversized* group since load markedly increases across all quartiles: 60% in the lower quartile, 24% at the median and also 45% in the upper quartile. These are evidence of a substantial rebound for these households (in agreement with our previous work Boccard and Gautier, 2021).

Quantile	25%	25%	50%	50%	75%	75%
Electricity	Before	After	Before	After	Before	After
Full Sample	6.2	9.4	12.1	13.3	30.2	30.1
Undersized	7.4	8.0	12.7	12.8	31.1	29.8
Oversized	6.0	9.6	11.3	14.0	22.8	33.2

Table 2: Power load in kWh/day around PV installation

Natural gas Table 3 next displays our preliminary evidence for changes in the consumption of natural gas; we observe an 8.5% fall at the median of the full sample, thus indicating a partial displacement of natural gas by "free" solar electricity. Interestingly, there is no noticeable difference between either load quantiles or PV sizing.

Quantile	25%	25%	50%	50%	75%	75%
Nat. Gas	Before	After	Before	After	Before	After
Full Sample	45.4	42.2	57.6	52.7	89.0	82.9
Undersized	48.0	44.8	57.4	52.9	88.3	82.5
Oversized	44.9	41.7	57.9	52.6	94.5	85.9

Table 3: Natural Gas consumption in kWh/day around PV installation

Energy Lastly, we compute the household total energy consumption by adding the two fuels. Overall, the median prosumer reduces her energy consumption by 5.4%, more so for *undersized* PV systems and less so for those who *oversized* their installation (because of the power rebound).

[10] For robustness, we perform the same analysis for the 38 000 prosumers who do not have a natural gas connection with RESA (either because it does not exists or because they don't want it). For this sample, similar to our previous work (Boccard and Gautier, 2021), we find a clear rebound with the same qualitative interpretation as in Table 2, although consumption figures are larger for these households who do not use gas. We note how those oversizing from a small load almost double their power load thanks to the PV addition.

Quantile	25%	25%	50%	50%	75%	75%
Energy	Before	After	Before	After	Before	After
Full Sample	51.6	51.5	69.8	66.0	119.3	113.1
Undersized	55.4	52.8	70.2	65.6	119.5	112.3
Oversized	50.9	51.3	69.2	66.6	117.3	119.1

Table 4: Energy consumption in kWh/day around PV installation

5.2 Simple Econometrics

We aim here to confirm the previous empirical finding. We estimate the variation of the consumption of natural gas around the PV installation date $\Delta q^g = q^g_a - q^g_b$ (in kWh) as a function of several variables: the variation in power load $\Delta q^e = q^e_a - q^e_b$ (in kWh), the PV installation size $\kappa = 720K\bar{\beta}$ (in kWh), an oversizing index $\theta = \mathbb{1}_{\kappa > q^b_e}(\kappa - q^b_e)$ (in kWh), the change in temperature as expressed by degree days $\Delta\zeta = \zeta_a - \zeta_b$, the evolution of the natural gas price p (EUR/MWh), the median income w in the statistical sector and a dummy s for having benefitted from a subsidy. The regression equation is thus

$$\Delta q^g = \alpha + \beta_1 \Delta q^e + \beta_2 \kappa + \beta_3 \theta + \beta_4 \Delta\zeta + \beta_5 p + \beta_6 w + \beta_7 s + \epsilon \tag{1}$$

with results shown in Table 5.

	Estimate	Standard Error	t Statistic	P Value
cte.	-538.626	50.940	-10.574	0.000
Subsidy	473.899	20.428	23.198	0.000
Income	8.200	1.640	5.002	0.000
DegDays	7.476	0.460	16.269	0.000
GasPrice	-4.245	0.513	-8.282	0.000
PVsize	-0.374	0.036	-10.283	0.000
Oversized	0.557	0.065	8.610	0.000
DeltaLoad	0.287	0.018	16.108	0.000

Table 5: Change in Natural Gas consumption

We observe that apart from the constant and income, all variables are highly significant. Crucially, the PV installation size has a large coefficient meaning that for every additional 3 kWh of PV output, natural gas consumption falls by one kWh (beware that since $q^g \approx 4q^e$, an installation covering the power load can only hope to cut 1/12 of the natural gas consumption). Beyond this, an increase in power load as well as oversizing positively impact Δq^g while cold weather and high price impact Δq^g negatively (as expected).

6 Panel data analysis

6.1 Specification

To better identify the specific consequences of becoming a prosumer on ex-post energy consumption, we run panel estimations, as we observe the consumption of consumers over a long period. For each prosumer i, living in statistical sector j, we construct a consumption variable q^l_{it} for the gas ($l = g$) and electricity ($l = e$) consumption at month t.

Our objective is to explain the gas consumption of i at month t, estimating the following equation:

$$q^g_{it} = \alpha_0 + \alpha_1 x_{it} + \alpha_2 x_{jt} + \alpha_3 x_t + \alpha_4 PV_{it} + \alpha_5 t + \alpha_6 (t-\tau)|_{t>\tau} + \mu_i + \epsilon_{it}. \quad (2)$$

Our specification includes individual and statistical sector time-varying characteristics (x_{it} and x_{jt}), a time-varying characteristic that is constant across individuals x_t, a variable PV_{it} that capture the influence of being prosumer, an individual fixed effect to capture all the unobservable characteristics of i (μ_i) and the error term (ϵ_{it}). In addition, we will include a time trend and prosumer specific time that starts at the installation date τ.

We have limited information on individual consumers. We include in the regressions the monthly electricity consumption as it is likely that in a given house, the consumptions of the two energy flows are positively correlated; we thus set $x_{it} = \{q^e_{it}\}$. All the other unobserved characteristics of i, except for the PV installation date and size, will be captured by the individual fixed effect μ_i. Next, income is likely to affect the consumption, directly and indirectly as the house size tends to increase with income. However income is only observed at the statistical level j; we thus proxy individual income by $x_{jt} = \{Income_{jt}\}$. Two additional variables possibly impacting gas consumption are gas price and temperature (proxied by the so-called degree-days variable). These however vary across time but not across space; we set $x_t = \{GasPrice_t, DegreeDays_t\}$. A key variable is the indicator for PV installation: if prosumers consume less gas after they install PV, we expect a negative coefficient for this variable. We shall use three distinct specifications. First, we use a dummy variable (PV_{it}) that is equal to 1 the month after the installation date τ and 0 before (*PV*). Second, we multiply this dummy variable by the PV capacity in kWp to construct a variable *PV size*. Third, we multiply PV_{it} by the dummy for the subsidy program: *Solwatt, Qualiwatt* and *No subsidy* to capture the possible differences between the different cohorts of prosumers.

We do not include time fixed effect, as we have time-varying explanatory variables, but we include in some specification a time trend to capture the long term evolution of consumptions and a specific time trend that starts at the PV installation date.

6.2 Descriptive statistics

The descriptive statistics for the chosen variables are displayed in Table 6.2.

	mean	sd	min	max
date	.	.	.	.
client	.	.	.	.
power	433.6	465.2	-532.0	8614.0
natgas	1747.0	1485.3	1.0	23851.0
pvsize	2.2	2.6	0.0	10.0
pvtime	0.3	13.0	0.0	2118.0
solwatt	28.3	39.6	0.0	183.0
qualiwatt	0.6	0.5	0.0	1.0
nosubsidy	0.1	0.3	0.0	1.0
past	0.3	0.5	0.0	1.0
income	503.4	673.8	-3133.9	49967.9
v12	27.9	5.0	18.1	55.3
gasprice	24.4	20.5	4.4	177.8
degreedays	148.1	131.9	0.0	492.7
N	2001520			

Table 6: Panel descriptive statistics

6.3 Results

We present nine different specifications for the results, three for each specification of the PV variable and, for each of them, different specifications with and without the time trend and the prosumer specific time trend. Results are shown in Tables 7 to 9. We note that across all specifications, variables DegreeDays and GasPrice are significant and have the expected sign. The gas price elasticity ranges between xx and xx, tbc.

In Table 7, we use the dummy variable for the PV installation. This variable is negative, meaning that prosumers consume less gas after they installed their solar panels, confirming that electricity partially substitutes for natural gas. The estimated coefficient is around 60, meaning that the gas consumption of a prosumer decreases by 3.5%.

We identify a decreasing time trend, meaning that within the group of current and future prosumers, the gas consumption decreases over time at about 2% per year. Interestingly, this decreasing trend becomes smaller once an household turns prosumer.

Finally, the income parameter is positive, once a time trend is included, implying that houses in richer neighborhood have a higher gas consumption. And, the coefficient for power is also positive, implying that the consumption of electricity and gas are correlated.

In Table 8, we use the PVSize variable. The coefficient of this variable is equal to 13.61, which is 4.5 times lower than the coefficient of the dummy variable PV. This result is consistent as the average PV size is 4.68 kWp. All the other results are comparable. In Table 9, we multiply the PV dummy with a dummy for the support scheme, distinguishing the most generous Solwatt, from the other two, Qualiwatt and non subsidy. We observe that the impact on gas consumption is the largest for the first waves of prosumers and the impact is non-significant for those who installed after 2018 and did not get any subsidy. These results corroborate the estimations with PV size that the reduction in gas consumption is larger for larger PV installations, and, as we discussed before, the subsidy programs, especially Solwatt gave incentives to increase the installation size.

	(1)	(2)	(3)
	FE1	FE2	FE3
Power	0.347***	0.367***	0.367***
	(0.02)	(0.02)	(0.02)
Income	0.805**	0.0345	0.0392
	(0.25)	(0.12)	(0.12)
GasPrice	-1.233***	-0.331***	-0.331***
	(0.10)	(0.06)	(0.06)
DegreeDays	2.256***	2.225***	2.225***
	(0.02)	(0.02)	(0.02)
PV	-316.4***	-91.31***	-90.85***
	(20.67)	(7.37)	(7.37)
Time		-3.360***	-3.356***
		(0.12)	(0.12)
PVtime			-0.830***
			(0.18)
Constant	1041.4***	1705.7***	1702.9***
	(137.19)	(71.31)	(71.77)
Observations	2001520	2001520	2001520
R^2	0.16	0.17	0.17

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7: Panel regressions: specification 1

	(1) FE1	(2) FE2	(3) FE3
Power	0.352***	0.372***	0.372***
	(0.02)	(0.02)	(0.02)
Income	0.772**	-0.0242	-0.0195
	(0.25)	(0.12)	(0.12)
GasPrice	-1.396***	-0.337***	-0.338***
	(0.11)	(0.06)	(0.06)
DegreeDays	2.258***	2.223***	2.223***
	(0.02)	(0.02)	(0.02)
PVsize	-62.56***	-22.42***	-22.27***
	(4.59)	(1.96)	(1.96)
Time		-3.355***	-3.352***
		(0.11)	(0.11)
PVtime			-0.759***
			(0.18)
Constant	1042.3***	1737.8***	1735.0***
	(136.68)	(69.15)	(69.44)
Observations	2001520	2001520	2001520
R^2	0.16	0.17	0.17

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8: Panel regressions: specification 2

	(1)	(2)	(3)
	FE1	FE2	FE3
power	0.233	0.227	0.227
	(0.12)	(0.12)	(0.12)
income	0	0	0
	(.)	(.)	(.)
pv	0	0	0
	(.)	(.)	(.)
GasPrice	-2.531***	-0.358*	-0.517***
	(0.15)	(0.14)	(0.14)
DegreeDays	2.528***	2.470***	2.465***
	(0.06)	(0.06)	(0.06)
time		-3.110***	-46.26***
		(0.08)	(4.01)
pvtime			42.52***
			(3.95)
Constant	1377.3***	1713.1***	-306.9
	(36.29)	(38.51)	(188.62)
Observations	2772610	2772610	2772610
R^2	0.05	0.05	0.05

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 9: Panel regressions: specification 3

7 Conclusions

TBD

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A Sample construction

In this section, we explain how we construct the electricity and gas consumption of household i at date d. When collecting meter readings (r) for household i at dates d_0 and d_1, their difference $Q = r_1 - r_0$ is billed to the household but needs to be distributed over the period. To do so, we use the daily measures s_d^e and s_d^g based on the SLP curves, giving the percentage of yearly consumption on a specific day d. Let $\sigma = \sum_{d_0 \le t \le d_1} s_t$ sum the SLP index over the billing period, the ratio s_d/σ gauges relative consumption intensity on day d. Hence, for each $d \in [d_0, d_1]$, we estimate the daily consumption to be $q_d = \frac{s_d}{\sigma} Q$.

For prosumers, the volumetric part of the electricity bill is the difference between the current index and the previous reading, unless negative, in which case it is nil. As already mentioned, the rollout of smart meters has been slow in Wallonia so that most meters in our sample are still mechanical ones. As a consequence, once PV panels are installed, the meter runs backward whenever the household's production exceeds its consumption and runs forward otherwise i.e., the meter only records the difference between the power injections and withdrawals.[11] Recall indeed that under *net-metering*, if a client consumes q MWh while her PV systems produces k MWh, the meter records the difference $q - k$ and she is billed $\max[q - k, 0]$ kWh. In the case of a production surplus $(k < q)$, there is no compensation from retailers or the grid and the power surplus is 'lost'. Hence, a prosumer can consume this power for free before the end of the billing period.

To recover the power consumption of a prosumer, we need to estimate its production k and add it to its recorded consumption $q - k$. To do so, we compute the daily solar PV output over the Liège region using the hourly output of connected solar plants over this area, published by the Belgian network operator ELIA since 2018. For prior times, we use the solar irradiance estimates computed by the JRC from satellite records. From these data, we construct a capacity factor β_d for each day.[12] A prosumer with a solar capacity of $\tilde{k}$ kWp produces $K = \sum_{d_0 \le d \le d_1} \beta_d \tilde{k}$ over the billing period. Hence, its daily power consumption is estimated as $q_d^e = \frac{s_d}{\sigma}(Q + K)$.

[11] Eventhough a smart meter records separately power withdrawal and injections, RESA still aggregates those readings to compute the billable amount.

[12] In the long run, the Liège solar capacity factor is 10.8% meaning that a 1 kWp PV panel produces $0.108 \times 8760 \approx 945$ kWh per year; reported on a daily basis, the average output is $\bar{\beta} = 2.6$ kWh.

B Control group

C To do list

- Verify the number of statistical sectors

- Verify the parallel trend assumption: For the panel data analysis, we need a control group of consumers, similar to prosumers (income, consumption levels but without PV). In an appendix, we have a method to construct such a sample by minimizing the distance between a prosumer and a similar consumer using multiple dimensions. The key issue is that we need the parallel trend assumption, that is, before PV adoption, the evolution of the consumption of the two groups should follow a parallel trend, it is more important that the trend is similar than the level is similar. If the parallel trend assumption is satisfied, then the control group is valid and the analysis is ok. Then, if the variable PV*Post is significant, it means that there is a change in consumption after adoption. There are several issues (we need to read the book by de Chaisemartin (https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4487202 or ask a good econometrician) with this TWFE model, but this should be a good basis for the start.

  To verify the parallel trend assumption, we should do an event study, to do so, we need to multiply the variable PV with the coefficient -2, -1, 1, 2 and the coefficients for before should be equal to zero (not statistically different from zero). Usually this is presented as a chart as in Beppler (see Figure 10). I think that it is better to do an event study than having a time trend.

- Be careful when we use the data from 2021 onward as with the Ukraine war, prices skyrocket and substantially affect gas consumption.