Slashing the surplus

How prosumers with smart metering respond to regulatory restrictions on self-consumption in Croatia

Kesselring, Anne ; Pelka, Sabine; Svetec, Erica ; Nad, Lucija ; Seebauer, Sebastian ; Skardelly, Sara ; Preuß, Sabine

Publication date
2023

Document Version
Final published version

Published in
Conference Proceedings

Citation (APA)
Kesselring, A., Pelka, S., Svetec, E., Nad, L., Seebauer, S., Skardelly, S., & Preuß, S. (2023). Slashing the surplus: How prosumers with smart metering respond to regulatory restrictions on self-consumption in Croatia. In M. Lopes, K. Matschoss, & T. Bouman (Eds.), *Conference Proceedings: BEHAVE 2023: The 7th European Conference on Behaviour Change for Energy Efficiency* (pp. 516-528). Rijksdienst voor Ondernemend Nederland (RVO).

Conference Proceedings

BEHAVE 2023

the 7th European Conference on Behaviour Change for Energy Efficiency

European Energy Network
A voluntary network of European energy agencies

Netherlands Enterprise Agency

Behave 2023
7th European Conference on Behaviour and Energy Efficiency

Slashing the surplus – how prosumers with smart metering respond to regulatory restrictions on self-consumption in Croatia

Anne Kesselring[1] *, Sabine Pelka[1,2], Erica Svetec[3], Lucija Nad[3] , Sebastian Seebauer[4] , Sara Skardelly[4] , and Sabine Preuß[1]

1: Fraunhofer ISI (Institute for Systems and Innovation Research)
Breslauer Strasse 48, 76139 Karlsruhe, Germany
*Corresponding: anne.kesselring@isi.fraunhofer.de, ORCID: 0000-0003-3743-7057

2: Energy and Industry Group, Faculty of Technology Policy and Management,
Delft University of Technology, Jaffalaan 5, 2628, BX, Delft, the Netherlands

3: Green Energy Cooperative / Zelena Energetska Zadruga (ZEZ)
Bukovačka Cesta 110, 10000 Zagreb, Croatia

4: Joanneum Research Forschungsgesellschaft, Institute for Climate, Energy Systems and Society
Waagner-Biro-Strasse 100, 8020 Graz, Austria

Keywords: Smart Metering, Home Energy Management System, Photovoltaic Curtailment, Prosumers, Self-Consumption

Abstract: *Smart metering and home energy management systems (HEMS) support households with roof-top photovoltaic (PV) to optimize self-consumption. These HEMS can convey subtle guidance for consumption shifts that address intuitive consumption routines. However, the efficacy of the guidance depends on the regulation of self-consumption. This presentation provides experimental evidence on the interplay between both for the case of Croatia, where households that produce more electricity than they consume over the year are automatically re-classified as renewable traders and have additional administrative duties, as well as less favorable tax treatment. This creates perverse incentives to reduce PV generation or increase energy consumption. We document strong behavioral reactions within a real-life field experiment, which was conducted as part of the larger Horizon 2020 project NUDGE. The project collected both survey and smart meter data, which allows for a comprehensive picture of the behavioral reaction. According to the survey wave before the end of the year, almost half of the participants considered curtailing their PV output. According to the smart meter data, a sizable share did indeed take action by shutting down production or by powering additional devices to reduce the surplus near the end of the calendar year. In the final survey wave, prosumers provide ex-post insights on the specific measures taken to reduce surplus. Finally, we discuss insights from the experiment regarding the transparency and control offered by the HEMS, as well as how this can influence household behavior regarding the regulatory framework.*

1. INTRODUCTION

Prosumers are increasingly recognized as players in the energy transition (European Environment Agency, 2022). Through digital tools like smart metering and Home Energy Management Systems (HEMS), they have the tools to optimize self-consumption by actively managing production and consumption (see Cappa et al., 2020). However, whether prosumers actually adopt such behavior depends heavily on the overarching regulatory frameworks. Policy makers must strike a balance between encouraging microgeneration in the residential sector through awareness measures and policy support, while also preventing the exploitation of tax systems by commercial agents. A key question is then how to treat "surplus" (European Commission, 2017): if prosumers feed in more energy than they consume, they are net producers and sell a (taxable) good in a market. Many policy frameworks therefore set boundaries on prosumers' regulatory status through limits on plant size, surplus, or output thresholds (e.g., Inês et al., 2020; Clastres et al., 2019). However, there is little empirical evidence to date on the behavioral reaction of prosumers with regard to these limits.

We study the interplay between information provision and prosumer regulation for the case of Croatia. Under the current net billing system, the regulatory status depends on whether prosumers produce more energy than they consume on an annual basis. If prosumers have a surplus at year-end, they are automatically re-classified to a less favorable regulatory status with larger administrative burden. Hence, prosumers have incentive to reduce any surplus, which in practice can be done in two ways. Either by powering down their PV plants, or by increasing their consumption. Both options run counter to the core objectives of energy policy to promote microgeneration and reduce energy consumption. We provide experimental evidence highlighting that prosumers make drastic short-term adjustments to reduce the surplus. The experiment was conducted as part of the larger Horizon 2020 project NUDGE, which mainly focused on information provision through a mobile app. Yet the policy framework emerged as a key factor shaping behavior, and the purpose of this paper is to document these effects. We use survey data on the awareness and self-reported action, both before and after the turn of the year. This is complemented with smart meter data, which reveal that participants did indeed take action to manage their surplus. Selected case studies show how some participants increased consumption, while others reduced production. To the best of our knowledge, we are the first to provide evidence of a voluntary curtailment – where prosumers shut down microgeneration due to incentives in the policy system rather than grid constraints. Our work also provides novel insights on the interplay between information incentives and regulatory incentives – which are typically studied in isolation by scholars in behavioral science and public economics.

While we document a specifically Croatian case study, we believe that the insights are highly policy-relevant and timely beyond the example. In public economics, it has long been recognized that notches – i.e. discrete jumps in the tax treatment – create strong incentives to distort behavior, and that such distortions imply high economic costs (for a review see Slemrod (2013)). Given that many countries have notches in energy policy and that most legislative entities are still in the process of formulating the regulatory frameworks for prosumers, there are many potential areas of transfer. The experience and example of Croatia can serve as an alert for other countries and other policies.

2. INSTITUTIONS & DATA

2.1. Policy Framework

From 2021 until the end of 2023, the Croatian legal framework consisted of two distinct regulatory models: the "self-consumption" model, which applied to households and public institutions, and the "final customer with own production" model, which encompassed all other customer categories, but can also include households. These models were established by the Law on Renewable Energy Sources and High-Efficiency Cogeneration (Article 51). For household PV systems, a household transitioned to the "final customer with own production" model if they exported more energy to the grid than they imported in a given year. Under this billing approach, surplus energy not self-consumed on-site is bought by suppliers at a minimum of 90% of the user's average electricity price. Unlike the "self-consumption" model, which allows netting within a month, this model does not offer any netting. This significantly impacts investment returns, typically resulting in a 30% decrease. Additionally, the status switch comes with increased compliance burden that also makes it undesirable from a non-monetary perspective. Surplus in the regulation is defined as grid-in minus grid-out. In practice, the policy leaves prosumers two margins of adjustment: increase energy consumption (i.e. increase grid-in) or reduce the PV plants' production (i.e. grid-out). Accordingly, those are the two main hypotheses for the empirical analysis.

However, amendments to the Law on the Electricity Market and Renewable Energy Sources were accepted in July 2023. The transitional period starting in 2024 allows prosumers to retain the simpler regulatory model, and the Ministry aims to formulate a new system by March 31, 2025, initiating its application on January 1, 2026.

2.2. Data

The data were collected as part of the Horizon 2020 project NUDGE. The main aim of the project was to study nudging, i.e. non-monetary incentives altering a subject's choice architecture, through the medium of an online application. In the Croatian pilot, the sample consisted of 82 participating households with rooftop PV in three cities, who all received information about their photovoltaic production, self-consumption and overall energy consumption through the *Sunči mobile app*. We focus here on the second intervention period, which was a feedback nudge implemented in the fall of 2022 and provided participants with timely information regarding their surplus, including accumulated values on a monthly and annual basis. The information delivered in the nudge project therefore created a new level of transparency and easier control over the regulatory status for each participant. This feature was made available to the participants from November 2022. To analyze the behavioral reaction, we use two data types: survey and smart meter (i.e. sensor) data.

We conducted two online surveys – one with 54 participants (running end of October 2022 to mid-December 2022) and another one with 80 participants (in April 2023). The surveys cover both socio-demographic and energy-related questions. Specifically, our analysis focuses on (i) behavior regarding the regulatory status (e.g. shut down PV plant, turn on other electricity appliances, change the heating system), (ii) the self-assessed energy consciousness of the

participants, and (iii) electricity consumption and self-consumption (intention and future behavior). In the second survey, the sample consisted mainly of men (93%, n = 76) and six female participants (7%) aged between 32 and 73 years (M_{age} = 48 years, SD = 12.35). All survey respondents owned their home (84% single-family detached houses) and had a PV panel installed as a pre-requisite for participation. The average household of the responding participants consisted of two adults aged between 20 and 64 years and one child under the age of 14 living in a home with 172m² (living space ranging from 64 to 630m²).
Smart meter data were collected continuously throughout the study period, for the analysis of the policy effects, we focus on the period from 1 June 2022 to 28 February 2023. The high-frequency data are aggregated to daily values and focus on two outcome variables. Production is the energy generated by the rooftop PV. Consumption is total household consumption, including self-consumption and energy drawn from the grid. All values are reported in kWh and refer to the mean of daily values within a 24-hour period. We exclude participants with long gaps in data transmission, but do not require a fully balanced panel.

2.3. Strategy for Data Analysis

We provide a descriptive analysis of the data that is motivated by the small sample and the expected heterogeneity in the individual reactions. The results are organized chronologically. We begin with the first survey wave to examine the prosumers awareness and intention with regard to the policy. Second, we compare these self-reported adjustments to the sensor data. We first look at the full sample, and subsequently choose 10 participants for case studies on the individual behavioral reaction in a time-series plot.[i] The results conclude with the final survey wave and a comparison across waves. Most questions are congruent across the survey waves, but we added questions on ex-post experiences in the final wave.
Unfortunately, not all participants answered each survey wave, and there were data transmission problems with some participants in the sensor data. This leaves a discrepancy between the survey sample and the sensor sample. We do not want to restrict the sample any further given the limited sample and proceed with all survey respondents in each wave. We then examine each participant's smart meter data and select prototypical cases for each type of reaction. The analysis sample is therefore inconsistent across the data types, but this was a conscious choice to give comprehensive insights on the policy given the data constraints.
We discuss five prototypical reactions to the regulatory policy, illustrating each reaction with the production and consumption patterns of two exemplary participants as case studies. Considering the very diverging reactions and small initial sample, we only focused on those participants where the reaction is tied to the intervention timing, in order to avoid spurious correlations. The figures in Section 3.2 give electricity produced by the participant's PV panel and electricity consumed by the participant (provided from the PV panel or from the grid) in kWh. Metered daily averages are converted to seven-day rolling means in order to correct for variance from weather conditions, household events or similar. Color-coding distinguishes the

[i] None of the households selected as case studies underwent any changes in their living situation that could be confounded with their observed changes in electricity production and consumption.

different phases: Blue for pre-intervention, black during intervention, red after intervention and green for the new calendar year of 2023. As the timing of the intervention varies between participants, vertical dashed lines indicate when the intervention took place for the respective participant. Additional information from the survey data is used to interpret the observed production and consumption trends in each case study participant.

3. EMPIRICAL RESULTS

3.1. Results from Survey Wave 1 on Policy-Related Behavior

Participants were asked to report their policy-related behavior by implementing five variables (all single items). Specifically, we asked participants about their self-consumption, whether they turned on additional appliances to buffer PV over-production and whether they shut down the PV plant to avoid the status change. Only in wave 2, we asked whether participants changed their heating system, as this may also drive up electricity consumption (system-dependent), and whether their regulatory status actually changed in 2023. The descriptive statistics for the common questions in both waves are displayed in Table 1.

Table 1: Descriptive statistics for survey wave 1 and 2 on policy-related behavior

	Survey wave 1 (n = 54)			Survey wave 2 (n = 80)		
Increased self-consumption -2 = decreased a lot, 2 = increased a lot	M (SD) = 0.53 (0.94) n = 49	Min, Max = -2, 2 (range = -2, 2)	"I am not sure": 6% (n = 5)	M (SD) = 0.38 (0.97) n = 78	Min, Max = -2, 2 (range = -2, 2)	"I am not sure": 2% (n = 2)
Turning on additional electrical appliances	Yes: 61% (n = 33)	No: 26% (n = 17)	Other: 13% (n = 7)	Yes: 63% (n = 50)	No: 23% (n = 18)	Other: 15% (n = 12)
Shutting down the PV plant	Yes: 44% (n = 24)	No: 41% (n = 22)	Other: 15% (n = 8)	Yes: 43% (n = 34)	No: 50% (n = 40)	Other: 8% (n = 6)

During the fall (wave 1), the results indicate no or only a little increase of self-reported PV energy use. This is out of line with the initial objective of the app to nudge self-consumption. By contrast, most participants reported to turn on additional electrical appliances during hours of high PV generation. This serves both a direct financial benefit and the alignment of consumption patterns to the regulatory incentive. The survey also reveals high awareness of the policy. Almost half of the participants considered shutting down their production, and only 15% did not have a clear opinion. In this context, it is noteworthy that the dimensioning of the PV plant during installation is a key determinant on whether participants will be at risk of running a surplus, so it is not surprising that a substantial fraction answered "No". The category *Other* includes the option "I did not think about it" to distinguish. The sample is rather evenly split on whether they consider self-curtailment, which indicates that the policy creates segmentation depending on the households' PV installation and equipment.

3.2. Results from Sensor Data on Prototypical Reactions

For each of the five prototypical reactions, we present the two case studies side-by-side. The dashed lines indicate the intervention start (double line if activation occurred over two days), and the break from red to green marks the end of the year.

Temporary shutdown of the PV plant until year-end —. Participants 2 and 14, as can be seen from the drop in the red production line, temporarily shut down their PV system, a step they had mentioned in the survey. During the shutdown, participant 2 strived to increase electricity consumption by installing an electric boiler to substitute for gas in hot water heating and by switching on additional appliances at times when the PV system produced more electricity than the household could consume. Participant 2 also strongly disagreed that they had made any attempts to save electricity at home in the months after the intervention. By contrast, participant 14 shut down PV production and maintained consumption as before (apart from a short peak towards year-end). In both surveys, participant 14 emphasised that they intended to and tried to save electricity at home; moreover, they did not switch on any extra electrical appliances when the power plant was producing much more electricity. These responses stated by participant 14 do not correspond with their sensor data; however, electricity saving efforts might have been levelled out by participant 14's low overall consumption level. Eventually, in 2023, participant 14 received the "self-consumption" status.

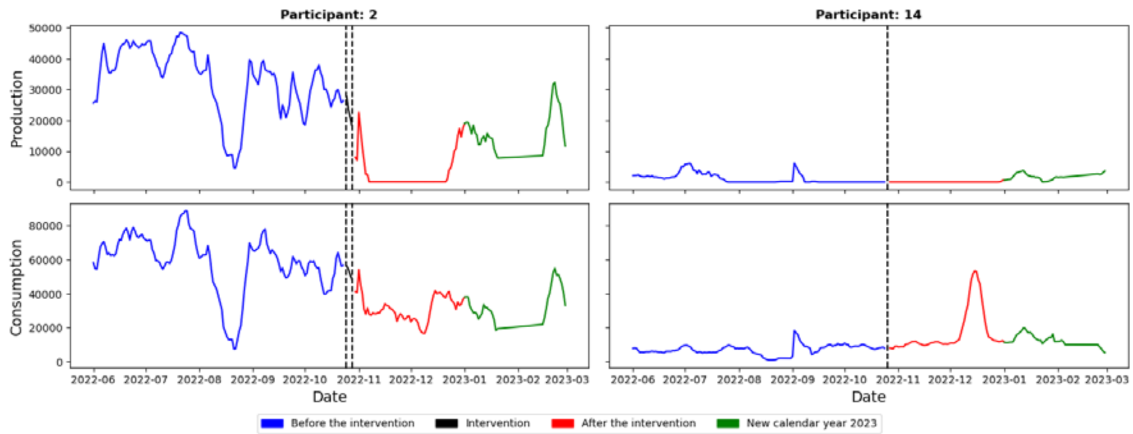

Figure 1. Temporary shut-down of PV plant in self-curtailment

Increase consumption until year-end —. Participants 19 and 43 showed a steep incline in electricity consumption immediately after the intervention, whereas their production remained unchanged or even decreased. After the turn of the year, their consumption returned to previous levels. Both participants expressed a strong intention to increase their own PV electricity consumption and strongly disagreed with trying to save more electricity at home in the three months following the intervention. They reported that they frequently used appliances when production exceeded consumption, with participant 19 using a washing machine, heat pump and clothes dryer, and participant 43 using air conditioning and electric heaters. Participant 43 explicitly stated that they did not consider the above reaction of shutting down the PV system temporarily, but instead decided to increase their consumption in order to balance their overall production-consumption ratio.

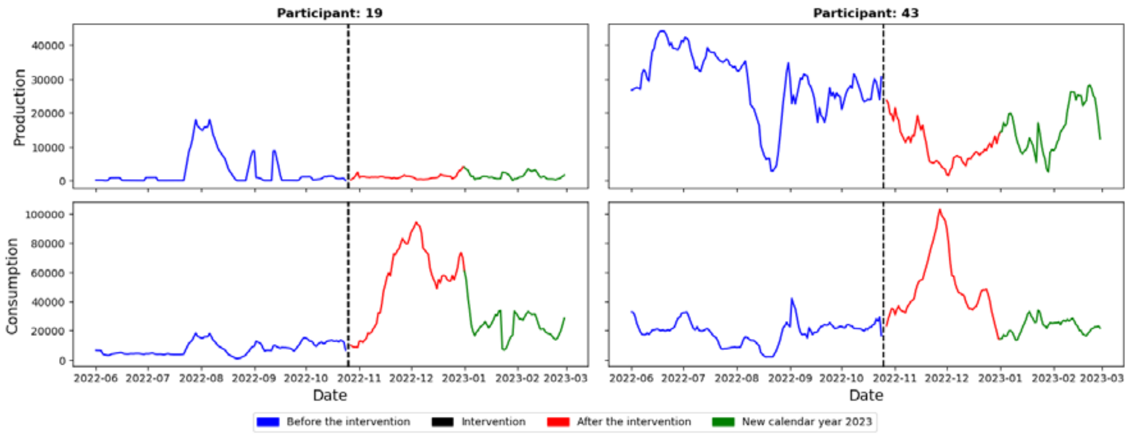

Figure 2. Increase consumption through additional appliances

Decrease consumption and maintain beyond year-end —. Participants 38 and 40 exemplified a persistent reduction in electricity consumption beyond the turn of the year. Participant 38 stopped using the electric boiler and opted for winter mode, i.e. a switch to an alternative heating method during the cold season. Both participants dismissed the option of turning on additional devices when production exceeded consumption; participant 40 even rejected this notion strongly. The electricity saving efforts of participants 38 and 40 as observed in the sensor data were consistent with their survey responses: both intended to save more electricity and use more PV energy after the intervention; both stated that saving energy made them feel good; and both described themselves as rather energy-aware households.

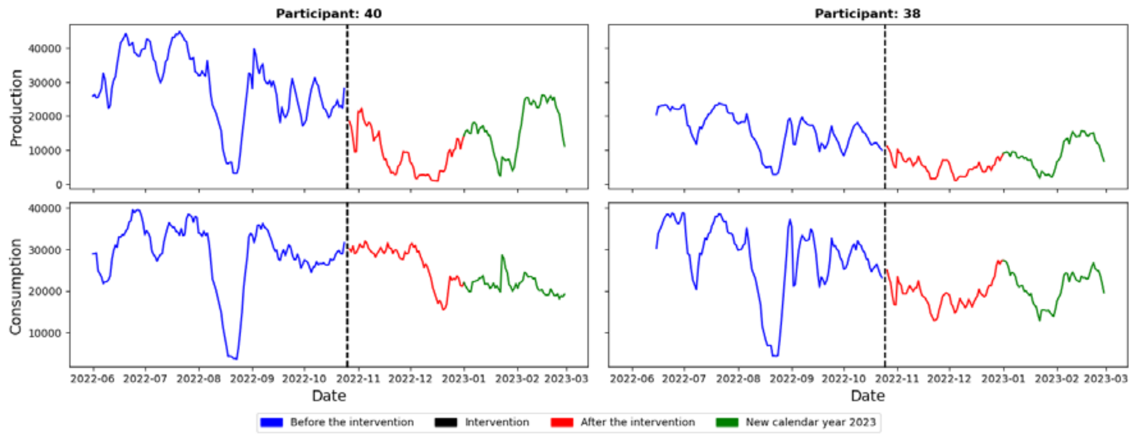

Figure 3. Continued decrease into the new year

Decrease consumption but bounce back with the new year —. Participants 46 and 48 decreased or at least maintained their electricity consumption after the intervention, but by the turn of the year, their consumption increased remarkably, even exceeding their previous levels and partly mirroring their production pattern. At the time of the intervention, participants 46 and 48 stated strong intentions for saving electricity in the next three months, but rather for reducing energy costs than for avoiding feelings of guilt. At the subsequent survey, participant 48 had abandoned their intentions for further saving energy. Both participants aimed for self-consuming more PV electricity instead and leveraging eventual production surplus; to this end, participant 46 planned to use less gas and to charge an electric vehicle, and to consequently reduce carbon emissions.

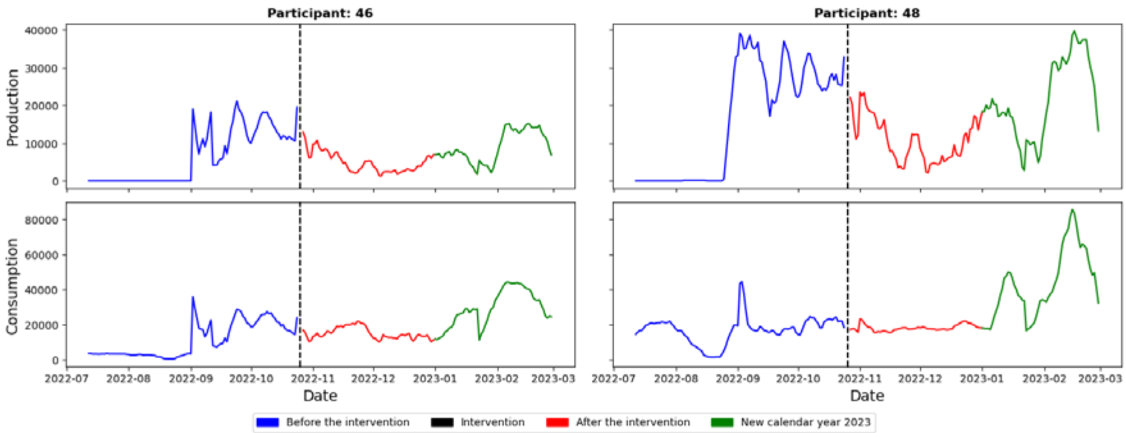

Figure 4 Decrease consumption only temporarily until year end

No reaction —.Participants 44 and 45 served as examples for a lack of visible reaction to the policy. This does not ascertain that they were not aware, random fluctuations in production and consumption might mask subtle underlying reactions. Both participants did not commit to electricity saving intentions or attitudes in either survey: They neither agreed nor disagreed with the statement on guilt about not saving energy. At the time of the intervention, they neither agreed nor disagreed with statements on trying to save or having already saved electricity. Participant 44 stated neutral intentions towards saving electricity in the three months after the intervention. Both participants replied "I am not sure" in their self-assessment whether their carbon emissions had decreased in the last three months.

There are several other participants with similar time series plots in the overall sample, while for other households there are only weak tendencies, which does not allow proper categorization. We deliberately chose two cases for each type to characterize the range of identified reactions and underscore the heterogeneity.

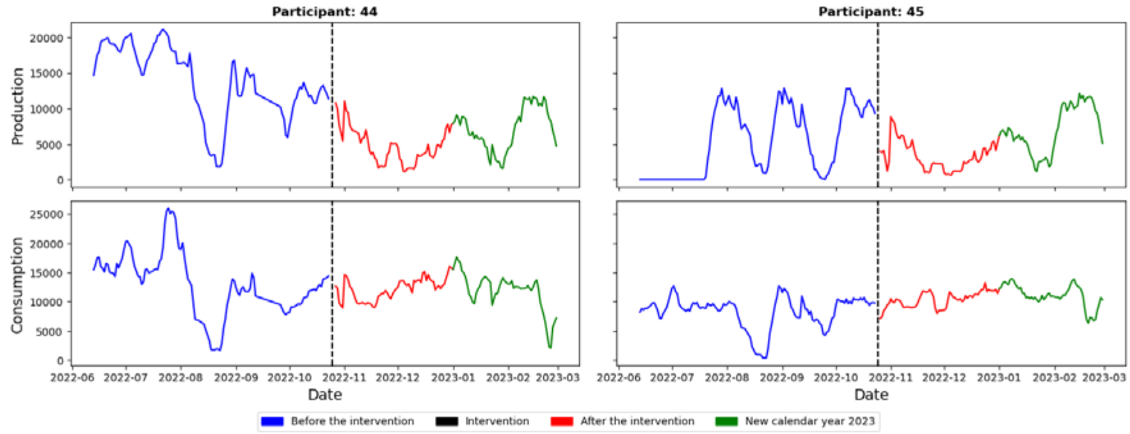

Figure 5. No visible reaction during the intervention period

3.3. Results from Ex-Post Survey Analysis

In spring 2023, we asked participants in a second survey wave the same questions as in wave 1 to assess potential differences and provide a policy evaluation.

3.3.1. Results from Survey Wave 2

For the self-curtailment behavior, the descriptive statistics for survey wave 2 show that participants perceive their self-consumption to be unchanged or increased a little over the first quarter of 2023 (see Table 1 in 3.1). Even in the spring, a large proportion of the participants (43%) stated that they considered shutting down the PV plant to avoid the status change. Moreover, the majority (61%) reported to have turned on additional appliances to achieve savings despite the over-production of their PV power plant. Similarly, only 28% of participants in wave 2 stated to have *not* changed their heating system. 50% (n = 40) reported that they started to occasionally heat with electricity (air conditioner or electricity heaters), 14% (n = 11) reported to use a heat pump since the installation of the PV plant, 5% (n = 4) replaced the gas boiler with an electric one, and 4% (n = 3) chose “Other”. These results fit with the other self-curtailment variables and indicate an increase in electricity consumption by most participants after the installation of the PV plant, which points to rebound effects that are indeed incentivized by the policy.

Notably, the responses for increasing consumption and shutting down the plant are on par with those from the fall. Applying a paired t-test as an inference statistical comparison of the self-consumption variable (with n = 48) shows no significant difference. However, the small sample size may limit the comparative analysis. Examining the cross-tables (automatically excluding participants who did not answer the same question in both surveys), it emerges descriptively that only eleven participants (26%) changed their answers across time regarding the shut-down of their PV plant (from yes to no or vice versa, n = 43). The same pattern results for the question to turn on an additional appliance (n = 44): 12 participants (27%) changed their response between survey wave 1 and 2.

Finally, in wave 2 we asked whether participants' status had changed at year-end and why (question is omitted from table, multi-response was possible). Only 3 participants (4%) experienced a status change – one participant reported having over-dimensioned the plant in the installation, the others attributed the status change to not using the PV plant enough. The most common response (46%, n = 37) was that participants felt they avoided the switch thanks to the correct dimensioning of their plant. The distribution of responses fits with the sensor data, where not all individual participants show strong reaction, but those that react do so drastically. While 9% (n = 7) of participants reported that they had actually engaged in self-curtailment (turned off PV plant), 19% (n = 15) reported that changing the heating source to electricity helped them avoid the switch. 4% (n = 3) bought an electric vehicle.

3.3.2. Before-After Comparison of Electricity Consumption Questions

In both survey waves in fall 2022 and spring 2023, we also asked participants about their electricity consumption behavior. Specifically, for the electricity consumption and their PV self-consumption, we implemented questions on the intention to save electricity (three items, Cronbach's alpha = .92 and .90, in wave 1 and 2 respectively) and the intention to use more PV energy (three items, Cronbach's alpha = .90 and .93), as well as their expected increase in electricity consumption and self-consumption (one item each). The descriptive statistics of these variables for both waves are displayed in Table 2.

Table 2. Descriptive statistics for survey wave 1 and 2 on electricity consumption behavior

	Survey wave 1 (n = 54)			Survey wave 2 (n = 80)	
	M (SD)	Min, Max (range)	Scale interpretation: Higher values indicate ...	M (SD)	Min, Max (range)
Self-assessed energy consciousness	7.24 (1.32)	5, 9 (1, 9)	higher energy consciousness	7.34 (1.25)	4, 9 (1, 9)
Intention for electricity saving (electricity consumption)	3.56 (1.08)	1, 5 (1, 5)	higher intention to save electricity	3.60 (0.99)	1, 5 (1, 5)
Intention for PV energy use (self-consumption)	3.83 (1.10)	1, 5 (1, 5)	higher intention to use PV energy	3.85 (0.98)	1, 5 (1, 5)
Expected increase in electricity consumption	1.48 (2.44)	-4, 4 (-4, 4)	expectation of higher consumption	0.69 (2.43)	-4, 4 (-4, 4)
Expected increase in PV self-consumption	1.50 (2.15)	-4, 4 (-4, 4)	expectation of higher self-consumption	1.23 (2.30)	-4, 4 (-4, 4)

The first note is the high starting motivation (above mid-scale in wave 1). When conducting paired t-tests for the electricity behavior variables between waves (with $n = 54$), none of the five t-tests reaches the statistical level of significance. Thus, none of the described variables changed significantly over time. However, descriptively, we observe a trend over time in an electricity-conscious positive direction. There is a slight increase in the intention to save electricity and to use more own production. The energy consciousness increases slightly on average. There is a decrease both in the mean for expected increase in electricity consumption and in the expected PV self-consumption. The latter is not in line with the other descriptive developments. We also examined the correlations within each wave and found positive correlations between the intention to save electricity and the intention to use PV energy (wave 1: $r = .62$, $p <.001$ and wave 2: $r = .66$, $p <.001$), and between the expected increase of consumption and self-consumption (wave 1: $r = .84$, $p < .001$ and wave 2: $r = .71$, $p < .001$). In wave 2, the self-assessed energy consciousness and the intention to save electricity have a small correlation ($r = .25$, $p = .028$). All other correlations were not significant. Overall, there is no strong evidence for a significant effect of the policy on the underlying electricity consumption behaviour. We take this as indicative of a disconnect between short-term adjustment and long-term behavioral change. However, we acknowledge that the small sample size limits statistical inference and constrains the external validity of the results.

4. DISCUSSION & CONCLUSION

4.1. Policy Implications

The interventions in the NUDGE project were initially intended to provide intuitive guidance that leads consumers to adapt everyday choices (see Thaler and Sunstein, 2009). The Croatian case, however, reveals that the information provided through the nudge served a different purpose. The information in the app became a transparency and control mechanism that allowed prosumers to monitor the regulatory conditions. Reminders are known to be effective for tax compliance (e.g., Ericson, 2017), but the link is new for energy policy. On the one hand, this indicates that nudging and similar information schemes can have a positive co-benefit: transparency. Policy measures that are designed for the intuitive behavioral system can have positive linkages to the rational system. On the other hand, the lesson is that nudging interventions have limited efficacy for their original objective of intuitive guidance when the regulatory framework is dominant. The observed reactions do not reflect adjustments to everyday choices, but rather short-term adjustments to a regulatory notch. We discovered this interdependence in the course of the NUDGE project, but our experiment was not specifically designed for this purpose. This admittedly limits our analysis in terms of methodology and scope. For example, we focus on short-term adjustments that can be directly related to the nudge timing. The analysis cannot capture participants that adjusted gradually throughout the year without reliance on the additional nudge information, which is why we selected the 10 case studies. Similarly, the survey included questions related to the policy, but this was not the main focus initially. Future research will be needed to provide a better understanding of the channels and mechanisms through which nudging might provide co-benefits to regulation.

Prosumers' behavioral reactions reveal the nexus between rigid regulatory frameworks and "soft" measures aimed at consumer awareness. Our study depicts an example where these two approaches intersect. Importantly, it is only through this intersection that we observe substantial changes in behavior. The policy *notch* provides strong economic incentives to adjust production and consumption. The *nudge* subsequently made prosumers aware of their status at a crucial point in the timeline (end-of-year). The result is a swift and drastic reaction by those participants that had thus far underutilized their production. In order to avoid the status switch, prosumers increase energy consumption and curtail production as hypothesized, but there is more heterogeneity in the observed reaction than expected. Prosumers differ in their reaction in the sensor data, which is also reflected in the distribution of self-reported reaction strategies in the survey. Taken together, this suggests that there is no one-size-fits-all adjustment, as the individual behavioral reactions are influenced by technical equipment. With this background, it is important to emphasize that a large fraction of consumer avoided any repercussions because their PV plant was correctly sized. This puts importance to the pre-ceding investment decision, where private companies implicitly take on responsibility for setting a path to regulatory compliance, for which they may not have economic incentives.

In this context, it also appropriate to consider the policy effects from the perspective of the local collective. The project partner, Croatian energy cooperative ZEZ, has a general interest in building up energy communities. Yet with the policy reaction, the smart meter data collected from existing customers are potentially biased downward in their capacity to produce and share renewable energy. The distortion created by the adjustment to the policy hence prevents local organizations from effectively using the collected data as a building block for future business models, especially when the regulatory framework is subject to frequent revision and uncertainty as in the Croatian case.

4.2. Conclusion

In principle, both nudging and regulation could be used to support the overarching objective of energy policy for prosumers, namely increasing domestic PV generation and encouraging self-consumption. Yet, the outcome does not match the overall target in the Croatian policy framework. We hence encourage policy makers to consider the potential of nudging to be aligned with regulatory frameworks and tax systems, since our results suggest that there is opportunity to leverage the intersection to create synergies. This would allow individual prosumers to better utilize the very different types of incentives that are ultimately intended to promote distributed energy resources and private households' participation in the energy transition, which saves resources and expands renewables.

On the aggregate level, prosumers collectively contribute to economy-wide green priorities. We can only look at individual cases with our small sample, but the results suggest that the policy setting is likely to have substantial aggregate effects. If our findings are representative of the Croatian population, the policy results in lost renewable energy potential and excess energy consumption. If our results are *not* representative, i.e. prosumers without the app do not manage to avoid the status switch, there would be high economic costs from sub-optimal choices and excess compliance burden. Our study does not quantify the full economic cost, but both scenarios imply a substantial welfare loss. This is especially concerning regarding the observed self-curtailment. Curtailment has been studied mainly from a technical perspective, where the question is how grid constraints can be managed effectively and efficiently. Our results point to a different, paradoxical type of curtailment: prosumers who voluntarily shut off their production to comply with a regulatory system that is meant to promote precisely this production.

More broadly, our results are a warning sign that tax systems, regulatory frameworks, and energy policy are intertwined. When new actors and business models emerge in a transition period, existing and emerging legislation should be reviewed for alignment to avoid undesirable consequences. This is not only a task for policy makers, but also a general call to behavioral scholars to share knowledge: economists know notches, psychologists know nudges, and engineers know technology. In the Croatian case, these three sciences came together to analyze and understand the policy effects. Likewise, we believe the Croatian case can be informative across country boundaries, as European stakeholders scramble together to devise and evaluate the policy puzzle needed for the energy transition.

5. REFERENCES

Cappa, F., Rosso, F., Giustiniano, L., & Porfiri, M. (2020). Nudging and citizen science: The effectiveness of feedback in energy-demand management. *Journal of Environmental Management*, *269*, 110759.

Clastres, C., Percebois, J., Rebenaque, O., & Solier, B. (2019). Cross subsidies across electricity network users from renewable self-consumption. *Utilities Policy, 59*, 100925. DOI: 10.1016/j.jup.2019.100925.

Ericson, K. M. (2017). On the interaction of memory and procrastination: Implications for reminders, deadlines, and empirical estimation. *Journal of the European Economic Association*, *15*(3), 692-719.

European Commission (2017). Opinion of the European Economic and Social Committee on ‘Prosumer Energy and Prosumer Power Cooperatives’: opportunities and challenges in the EU countries. *Official Journal of the European Union, C34,* 44–52. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016IE1190.

European Environment Agency (2022). Energy prosumers in Europe. Citizen participation in the energy transition (EEA report, 01/2022). Publications Office of the European Union.

Inês, C., Guilherme, P. L., Esther, M. G., Swantje, G., Stephen, H., & Lars, H. (2020). Regulatory challenges and opportunities for collective renewable energy prosumers in the EU. *Energy Policy*, *138*, 111212. DOI: 10.1016/j.enpol.2019.111212.

Slemrod, J. (2013). Buenas notches: lines and notches in tax system design. *eJournal of Tax Research*, *11*, 259–283.

Thaler, R. H., & Sunstein, C. R. (2009). *Nudge: Improving decisions about health, wealth, and happiness*. Penguin.

Conference Proceedings

BEHAVE 2023

the 7th European Conference on Behaviour Change for Energy Efficiency

European Energy Network
A voluntary network of European energy agencies

Netherlands Enterprise Agency

Behave 2023
7th European Conference on Behaviour and Energy Efficiency