The sun as an investment: What could happen when subsidies disappear?

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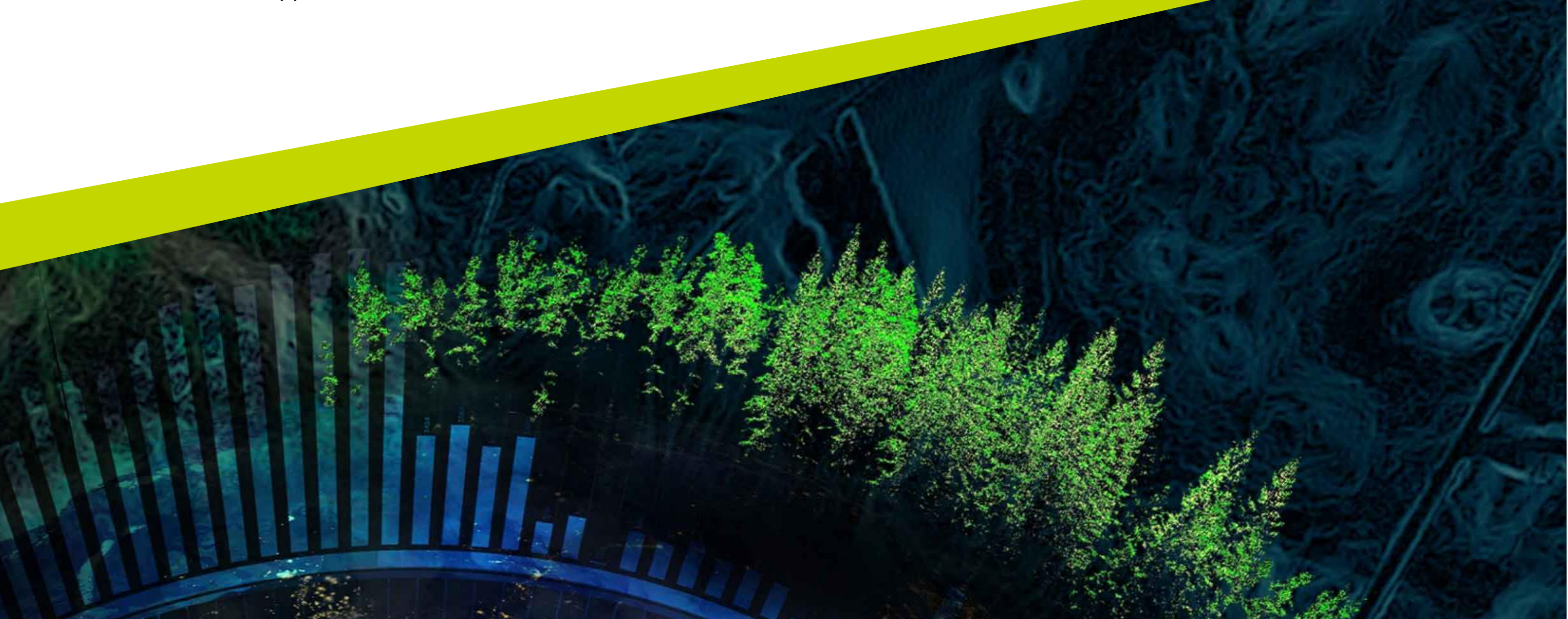

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Abstract

The study investigates the effect of government investment subsidies for solar panels on household investment behavior and electricity consumption in single-family homes in Sweden. Using panel data from 2010 to 2023 across Swedish counties, a quantitative approach is applied by combining Fixed Effects regression with a Difference-in-Differences design to estimate both direct and indirect effects of a subsidy form.

Results show that the removal of the investment subsidy in 2021 led to a statistically significant decrease in both the number of solar panel installations and installed capacity. On average, the number of new installations per county declined by approximately 3.8 units annually, representing a drop of up to 25-35% in some regions. Although no significant direct effect on electricity consumption was observed, the analysis reveals a clear indirect effect. Households that installed solar panels reduced their electricity consumption from the grid by an average of 1.77% per additional installation.

The findings indicate that government subsidies play a critical role in driving technology adaptation and indirectly influence household energy behaviour. The study highlights the importance of considering both technical and behavioural mechanisms in the evaluation of climate policy instruments and supports the design of long-term, economically effective, and socially inclusive renewable energy policies.

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1. Introduction

A transition from fossil fuels to renewable energy sources is crucial to achieving the climate goals of the Paris Agreement and Sweden's ambition of net-zero green gas emissions by 2045. In this transition, solar energy plays an increasingly important role, especially in small-scale, decentrialized electricity production, where it can be substitute or complement fossil-based energy. To promote this development, many countries, including Sweden, have introduced government subsidies to reduce financial barriers for households investing in solar cell systems.

During the period 2009-2020, a government investment support for solar cells (investeringsstöd för solceller) was applied in Sweden, which was later replaced by a tax reduction for green technology adoption and change consumption behavior. While critics argue that such support systems risk being inefficient or biased, proponents highlight their role in helping households overcome both economic and psychological barriers to investing in renewable energy. However, knowledge about the actual effects of these policy instruments on small households' renewable energy consumption remains limited.

Despite growing interest in solar energy, there is still a lack of empirical knowledge about how these subsidies actually affect households' investment decisions and energy use over time. It is particularly important to understand whether the subsidies lead to long-term changes in electricity consumption through increased self-sufficiency or whether the effects are limited to the installation level. It is also relevant to analyze which mechanisms mediate these effects, for example, whether it is the decision to install or the capacity of the installation that is decisive for the change in household behavior.
Against this background, this study aims to examine how government investment subsidies for solar cells have affected the use of renewable energy among Swedish households with single-family homes. Using panel data for the counties of Sweden during the period 2010-2024, and a combined method that consists of Fixed effects regressions and a Difference-in-Differences design, both direct and indirect effects of the subsidy reform are analyzed. The focus is on three outcome variables: number of installations, installed solar cell capacity, and household electricity consumption.

The study thus contributes to the growing literature on climate policy instruments and the role of households in the energy transition, and provides a basis for the design of future support models for renewable energy.

1.1 Research question

This study investigates the effect of government subsidies for solar cell systems on the use of renewable energy in single-family homes. The research focuses in particular on whether, and to what extent, financial incentives in the form of investment support affect households' decisions to invest in solar cell technology and how these instruments in turn affect electricity consumption.

Given that solar cell systems represent a concrete opportunity for single-family homeowners to reduce their dependence on electricity from fossil sources, it is crucial to understand how policy instruments such as subsidies affect both technology diffusion and energy behavior. Previous research has shows that high initial costs often constitute a barrier to investments in green technology (De Groote & Verboven, 2019; Karlsson, 2024), and that subsidies can serve as a key to lowering the threshold for adoption.

The research question for this study is formulated as follows: Do solar panel subsidies influence single-family households' electricity use directly or through investment behavior?

2. Background

2.1.1. Transition from investment support to tax reduction

After over a decade of direct investment support, the Swedish government chose to phase out the solar cell support in 2020. The previous system was then replaced by a new form of economic incentive, tax reduction for green technology. This meant that the support was instead given as a direct deduction on the cost, similar to the established ROT deduction for renovations. For solar cell installations, the deduction was initially set at 15% of the investment amount (Government, 2023).

The reformed aimed to simplify the application process and improve liquidity for households, as the deduction could be made directly upon purchase instead of being paid out afterwards. In 2023, the deduction was temporarily increased to 20%, which, combined with continued price pressure and increased climate awareness, led to a record-high expansion. At the end of 2023, there were over 250,000 grid-connected solar cell systems in Sweden. This is a significant increase compared to previous years (Government, 2023).

The government has subsequently assessed that the solar cell market is now more self-sustaining and has announced that the subsidy level will be reduced back to 15% from the summer of 2025. In addition, a gradual phase-out of other tax breaks linked to small-scale electricity production is planned, such as tax exemption for the sale of surplus electricity (Government, 2023). This development indicates how the role of support systems has changed over time. From being a crucial tool for starting market development to being gradually phased out as the technology matures and becomes economically competitive, even without subsidies.
These changes motivate an investigation into the introduction of the first investment support for solar cells in Sweden, and an assessment of its significance to Swedish households.

2.1.2. Development and the importance of solar cell technology

The past two decades, solar cell technology has undergone rapid development, making solar cells an increasingly competitive option for households wishing to contribute to the transition to a more sustainable energy system. In particular, rooftop installations have become more and more popular. Especially when the price has declined from the installation of solar cells during the 2010s. This cost reduction has largely been driven by technological advancements and global market. Expansion, supported in part by generous early subsidy programs (Nilsson, 2020). One example is Germany, which introduced fixed feed-in tariffs for solar electricity in 2003. These long-term guarantees boosted private investment and led to a sharp increase in solar capacity. Germany's policy is estimated to have had gloval effects, influencing solar adoption far beyond its borders (Nilsson, 2020). However, the German case also highlights the need to adapt support systems over time. When subsidies were reduced in 2012, the rate of new installations slowed significantly. This experience has influenced other countries, including Sweden, to design and adjust their solar support schemes in response to evolving technology and market conditions.

2.1.3 Subsidies and support systems in Sweden

Sweden has various forms of government subsidies that have been used for the promotion of the expansion of solar energy. In 2009, an investment subsidy for solar cells was introduced, the so-called solar cell subsidy (Investeringsstöd för solceller). The aim was to increase the share of renewable energy in electricity production by making it easier for households and small operators to install solar cell systems (Nilsson, 2020). Initially, the level of support was very generous; the state reimbursed up to 60% of the investment costs. However, the support was limited to an annual budget of 95 million SEK, which quickly led to a very high level of interest and thus long processing times.

As the prices of solar cell systems then fell, partly as a result of international technological and market developments, the Swedish level of support was also reduced. Between 2011 and 2015, the subsidy was around 30%, and from 2019 it reduced to 20% (Nilsson, 2020). Despite this gradual reduction, interest in solar cells continued to increase sharply. This suggests that technological improvements and falling installation costs have made solar cells an economically attractive investment, though without a high subsidy rate. As early as 2015, the Swedish Energy Agency stated that the support should be phased out in line with continued price declines (Nilsson, 2020).

3. Litterature review

3.1 Previous research

3.1.1 Household investment behaviour and incentives

Previous research shows that households' decisions to invest in solar cell technology are strongly influenced by economic incentives, particularly in the form of subsidies and expected payback periods. A key aspect in this context is households' implicit discount rate. For example, how future energy savings are valued relative to initial costs. An influential study by De Groote and Verboven (2019) showed that households tend to apply an implicit discount rate of around 15% when deciding on solar cell investments. Such a high required rate of return means that investments are often considered unprofitable without public support, thus justifying government subsidies to improve short-term profitability.

The same study also found that the implicit discount rate varies depending on the economic circumstances of households, while households with higher incomes, on average, apply a slightly lower discount rate (around 10%). Low-income households often require an even higher return to justify investment (15% or more). This suggests that general solar cell subsidies in practice mainly attract financially stronger households, which has also been confirmed in empirical observations (De Groote & Verboven, 2019).

Several other studies confirm the importance of economic incentives and show that the demand for solar cells is sensitive to changes in price. Crago and Chernyakhovskiy (2017) identified a high price elasticity of solar cell investments, where subsidies were shown to have a particularly large effect among households that had previously refrained due to low profitability. The design of the support systems also affects which groups are reached. Experience from the USA shows, for example, that tax credits and ned debit programs initially benefited households with higher incomes to a greater extent. In order to improve social justice in the transition, some states have introduced targeted support programs or preferential loan terms for low- and middle-income earners. According to O´Shaughnessy et al. (2022), such efforts have been shown to be able to increase the use of technology in these groups.

3.1.2 Policy effectiveness and cost effectiveness

Another important part of the previous research focuses on how effective different types of policy instruments are in stimulating investments in solar cell technology, and how these compare in relation to cost-effectiveness. Investment subsidies and so-called feed-in tariffs have been successful in initial market growth and technological development (De Groote & Verboven, 2019). At the same time, generous support levels have in some cases led to overcompensation and high socio-economic costs. A well-known example is Germany, where the generous support system led to global price pressure on solar cells, but also to high initial subsidy costs per kilowatt-hour (kWh) produced (Crago & Chernyakhovskiy, 2017).

In Sweden, the National Audit Office and the Swedish Energy Agency, among others, have pointed out the need to adapt support levels as the technology matures, to avoid overstimulation once the market has started. Several researchers also emphasize the importance of policy predictability. For example, there was a clear wave of applications in Sweden in 2018 when it was announced that investment support would be reduced, which was followed by a clear slowdown the following year. An opposite pattern could be observed in Germany in 2012, when a drastic cut in compensation led to reduced investments (O´Shaughnessy et al., 2022).

The discussion about optimal policy design remains relevant in research. Some economists argue that a gradually tapered support, which is gradually phased out as technology costs fall, is most socioeconomically efficient. Others emphasize that if external benefits such as reduced emissions and technology learning are large enough, even initially generous subsidies can be justified because they contribute to lowering future costs globally (O´Shaughnessy et al., 2022).

3.1.3 Solar cell installations as a measure?

Research also shows that solar cells play a crucial role in our goal to reach sustainable development and reduce the usage of fossil fuel, in line with both the UN's global goals and Sweden's climate goal of being fossil-free by 2045. Solar energy is highlighted as a concrete way to produce fossil-free electricity, making solar cell installations a central measure for achieving these goals. (Karlsson, 2024)

Private households are identified as key players in the energy transition. According to Karlsson (2024), investments in solar cells by individual property owners can play a crucial role in the transition to a more sustainable energy system. Despite this, there are investment barriers that can hinder development. In particular, the high initial investment cost is highlighted as one of the biggest obstacles. At the same time, the study shows that there is significant economic potential through reduced electricity costs and the possibility of selling surplus electricity. Lack of awareness of this potential, combined with the perception that solar cells are expensive, can lead to fewer people choosing to invest (Karlsson, 2024)

To reduce these obstacles, the so-called green technology deduction was introduced on 1st January 2021. This deduction means that private individuals can deduct 15 percent of the cost of investing in solar cell systems. The subsidy constitutes a financial incentive that aims to facilitate and encourage the transition to renewable energy (Karlsson, 2024). The deduction lowers the total investment cost, which in turn affects the payback period and profitability of the investment.

In the current study, this deduction is included in the profitability calculations to provide a more realistic picture of economic conditions. By assuming a lower initial cost, it is shown how subsidies can make solar cell investments more attractive to private individuals (Karlsson, 2024). The study generally aims to give private individuals a better understanding of the economic potential of solar cells, to facilitate well-founded investment decisions.
One of the most important conclusions in the study is that profitability is greatly affected by which electricity area the property is located in and by the electricity price. These factors give large variations in possible savings. Although the subsidy is not directly mentioned in the conclusion about the importance of the electricity price, it affects the total investment cost, making it an indirect but important factor in the profitability analysis (Karlsson, 2024).

3.1.4 Electricity certificate system for households and electricity prices

Previous research shows that government financial support is a recurring feature in the energy sector in Europe, where the aim is to secure household energy supplies, reduce emissions, and stimulate investments in renewable energy sources. In Sweden, the electricity certificate system is a key example of such a policy instrument, the aim of which is to increase electricity production from renewable energy sources, including solar energy (Royal Swedish Academy of Sciences, 2013,)

The electricity certificate system works by awarding renewable electricity producers an electricity certificate for each megawatt hour (MWh) of electricity produced. These certificates can be sold to electricity suppliers, who, according to the law, have a so-called quota obligation - that is, an obligation to buy a certain proportion of electricity certificates for their electricity sales. This means that producers of renewable energy, such as solar energy, receive an additional income in addition to the regular sale of electricity, which creates a clear economic incentive to invest in renewable electricity production (Royal Swedish Academy of Sciences, 2013).

However, in practice, it is households and consumers who ultimately pay for the subsidies. Since electricity suppliers are obliged to purchase electricity certificates, this cost is passed on to consumers through the electricity price. The subsidy is thus financed indirectly via higher costs for end consumers, rather than through tax financing (Royal Swedish Academy of Sciences, 2013)
Furthermore, the report highlights that household electricity costs in Sweden consist of several components. energy tax, VAT, electricity certificate fee, costs for emission rights, electricity network fees, and the cost of electricity consumption itself, which can be variable or fixed (Royal Swedish Academy of Sciences, 2013). This illustrates how complex and politically driven the pricing mechanisms for electricity are, which also affects how consumers and producers act in the renewable energy market.

4. Data and method

4.1 Data

Descriptive Statistics

In this study, we collected single-family household solar energy adaptation data and electricity consumption from 2016 to 2024 across the 21 counties in Sweden.

Table 1: *Descriptive Statistics*

	(1)			
	mean	sd	min	max
Population	12.70532	.8132982	10.96825	14.72107
GDP	11.85802	.9174696	9.909072	14.47896
Electricity consumption	19.91418	.6626602	18.41853	21.43776
Solar cell capacity	10.346	1.466106	6.55108	13.65776
Electricity supply	20.67091	2.061242	14.55602	25.14396
Number of solar cells	7.617854	1.403803	3.7612	10.87188
Observations	189			

Table 1 presents a descriptive statistics for the main variables included in the empirical analysis. The statistics are based on 189 county-year observations covering the period 2010-2023. The tables reports the mean, standard deviation (sd), and minimum and maximum values for each variable. The purpose is to provide an overview of the distribution, central tendencies, and variability in the data prior to the regression analysis.

The dependent variables: Number of solar cell installations, Solar cell capacity, and electricity consumption, shows a substantial variation both across regions and over time, which supports the appropriatness of panel data approach. Notebly, electricity consumption is log-transformed to improve the linearity of the relationships and to handle skewness in the distribution. The average (log) electricity consumption is approximately 19.91, with a relatively narrow standard deviation, reflecting moderate variation between counties.

Population and GDP are log-transformed to facilitate interpretation and reduce heterskedasticity. The price electricity price and electricity supply variables reflect important strucutural and economic differences across counties, which may influence both investment behaviour and energy use. The independent variable, indicating Subsidy, indicating whether the investment support for solar panels wasin effect during a given year, has mean of 0.62, reflecting the fact that the subsidy was active during a majority of the years in the dataset

Data description

Table 2*: Data description*

Variable	Type	Description	Source
Number of solar cells	Dependent Variable	Number of newly installed solar cell systems in each county	The Energy Agency
Solar cell capacity	Dependent variable/ Mediator variable	Installed capacity of the solar cell systems (in kW or equivalent) in each county	The Energy Agency
Electricity consumption	Dependent variable	Total electricity consumption in single-family homes for heating and hot water, per county (in kWh), expressed in natural logarithm	The Energy Agency
Subsidy	Independent variable	The presence of the solar panel subsidy policy (Statligt investeringsstöd för solceller). It equals 1 for years and counties where the subsidy policy was wactive and 0 otherwise	Parliament
Number of single-family homes	Control variable	Number of single-family homes owned (not rented) in the county	SCB
Population	Control variable	Population size in natural logarithmic foirm	SCB
GDP	Control variable	Regional GDP at the county level (millions SEK) in natural logarithmic form – used as an indicator of the county's economic level.	SCB
Electricity supply	Control variable	Logged total eccess to electricity in the county – used as a proxy for energy infrastructure	SCB

Electricity price	Control variable	Average electricity price (SEK/kWh)	Energy Market Agency
Year		The calendar year	

4.2 Econometric model

$$Y_{it} = \beta_0 + \beta_1 * Subsidy_{it} + \gamma_i + \delta_t + \varepsilon_{it}$$

$Y_{it}$is the outcome variable for county i in year t, which may refer to the number of solar panel installations, installed capacity, or household electricity consumption. The variable $Subsidy_{it}$ is a binary indicator equal to 1 if the solar panel investment subsidy was in effect in county i during year t, and 0 otherwise.

γ_i represents county fixed effects, which controls for all unobserved, time-invariant characteristics specific to each county, δ_t captures year fixed effects. The error term ε_{it} captures all other unobserved factors affecting the outcome.

The coefficient of interest β_1, measures the within county effect of changes in subsidy status on the outcome variable, controlling for both time and county fixed effects. To ensure reliable inference, robust standards errors clustered at the county level are employed, correcting for potential heteroskedasticity and serial correlation within clusters.

4.3 Methodology

In this work, I apply a quantitative research approach by using a Fixed Effects Panel regression in combination with a Difference-in-Differences (DiD) design. This methodology is used to analyze causal relationships in panel data, i.e., data that follows several units (such as counties) over time. The purpose is to examine how a change in government support, in this case a subsidy system (investeringsstöd för solceller/ investment support for solar cells) for solar cells, affects, for example, installation quantities, capacity, and electricity consumption in single-family housing areas. To investigate the disappearance of the subsidy and how it affected single-family households.

Fixed Effects Panel Regression is a regression model that is used to control for all factors that are unique to each unit but constant over time. In practice, this means that each region is compared with itself over time. This makes it possible to focus on how changes within each unit, for example, a changed subsidy, affect an outcome variable such as the number of solar cell installations or electricity consumption

In my application, I used the fixed Effects model by including units (e.g., counties) and years as categorical variables in the regressions, which allows me to capture both unit-specific and time-related effects. This is also done by using robust standard errors that correct for heteroskedasticity and clustered observations. The second component of my method,

Difference-in-differences (DiD) is used to examine the causal effect of a specific policy change-in this case, the change in a subsidy system, represented by the variable Subsidy.
The DiD model is based on comparisons over time between a treated group (those affected by the subsidy change) and a control group (those not affected). The basic idea is that if the intervention had not occurred, both groups would have followed similar trends over time - the so-called parallel trends assumption.

In practice, this is done by creating a dummy variable that indicates when and where the subsidy changes. By including this in the regression, together with fixed effects for years and units, the average effect of the subsidy on the outcome variables is isolated.

To check the validity of the assumption of parallel trends, I have examined the development of the outcome variables before the policy change in the preliminary analysis through visual comparisons (trends over time) and comparison of mean values. This is crucial for interpreting the results from DiD as causal. Using this combination of methods, Fixed Effects to control for time-invariant properties and DiD to isolate the causal effect of the policy change. I can conduct a credible analysis of how government subsidies affect household behavior regarding solar energy. The models have been estimated using statistical software (STATA), where I have stepwise added control variables such as population, GDP per capita, electricity price, and past electricity consumption to ensure that the effects I measure are not confounded with other concurrent factors. My method is fundamentally based on established econometric principles, and the design is inspired by the methodological review in The Effect by Nick Huntington-Klein (2023), where both Fixed Effects and Difference-in-Differences are treated as central tools for causal inference in policy analysis.

5. Results

5.1 The influence of subsidy on the solar energy use

Table 3: *The influence of subsidy (investeringsstöd för solceller) on the number of solar cell installations*

	(1) Number of solar cells	(2) Solar cell capacity
Subsidy	-3.798***	-4.083***
	(0.384)	(0.392)
Number of solar cells	0.000*	0.000*
	(0.000)	(0.000)
Population	-5.827*	-5.561*
	(3.013)	(3.220)
GDP	0.308	-0.117
	(0.827)	(0.794)
Electricity supply	-0.049	-0.127
	(0.066)	(0.081)
Electricity price	-0.010***	-0.009***
	(0.001)	(0.001)
2016.year	0.000	0.000
	(.)	(.)
2017.year	0.514***	0.654***
	(0.079)	(0.101)
2018.year	1.090***	1.366***
	(0.110)	(0.124)
2019.year	1.714***	1.977***
	(0.162)	(0.177)
2020.year	1.958***	2.256***
	(0.167)	(0.197)
2021.year	2.645***	2.991***
	(0.269)	(0.282)
2022.year	0.000	0.000
	(.)	(.)
2023.year	0.000	0.000
	(.)	(.)
_cons	74.748**	82.313*
	(34.993)	(40.224)
N	112.000	112.000

Standard errors in parentheses * $p < .1$, ** $p < .05$, *** $p < .01$

Table 1 presents the results of two separate fixed effects regressions. Model 1 examines how the number of new solar cell installations (Number of Solar cells) is affected by the government investment subsidy (Subsidy), while Model 2 analyzes the effect on the total installed capacity (Solar cell capacity). In both models, the coefficient for Subsidy is negative and statistically significant at the 1% level (-3.798*** and -4.083***, respectively). This means that the removal of the subsidy is associated with a significant decrease in both the number of installations and the installed capacity, indicating that the previous government investment subsidy had a strong incentive effect.

Several control variables are also statistically significant. Electricity price is significantly negative in both models (-0.010*** and -0.009***), which may indicate that households react negatively to rising electricity prices by not installing solar cells, a result that runs counter to some economic models but which can be explained by uncertainty and initial investment cost. Population has a negative and weakly significant effect in both models, which is interesting, suggesting that larger population does not necessarily correlate with more installations, which could be due to urban conditions, more rental apartments, or lower availability of roof space.

5.2 Indirect effects of the subsidy on electricity use

***Table 4**: Impact of Subsidy on electricity consumption*

Electricity consumption	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
Subsidy	-.0074289	.0045816	-1.62	0.121	-0.017	.0021281
Population	.4115284	.0805296	5.11	0.000	0.24	.5795102
GDP	-.0309182	.0187347	-1.65	0.114	-.069998	.0081616
Electricity supply	-.0005559	.0010767	-0.52	0.611	-.003	.0016902
Electricity price	-.0000463	.0000249	-1.86	0.078	-.000098	5.71e-06
year						
2018	-.0005174	.0013391	-0.39	0.703	-.00331	.002276
2019	.0014775	.0015549	0.95	0.353	-.001766	.004721
2020	.0067565	.0021082	3.20	0.004	.0023589	.0111541
2021	.0142157	.0031447	4.52	0.000	.0076561	.0207753
2022	0	(omitted)				
2023	0	(omitted)				
_cons	15.03324	.8850801	16.99	0.000	13.187	16.87949

The results indicate that the removal of the Subsidy is associated with a decrease in household electricity consumption, but the effect is not statistically significant ($p > 0.1$). This means that we cannot draw any firm conclusion about a direct

causal relationship between the policy change and the change in household electricity consumption.
In contrast, Population shows a strongly positive and significant effect (0.4120, p < 0.01), confirming that electricity consumption increases with the size of the municipality. Electricity price shows a small, significant negative effect (-0.00005, p < 0.1), suggesting that households react somewhat to price changes. GDP has a significant effect. From a policy perspective, the results suggest that the change in subsidy alone is not sufficient to directly affect consumption patterns, at least in the short term. However, structural factors such as population and electricity price play a role.

5.3 Mechanism of the subsidy effect

Table 5: *Indirect effect via installations: Number of solar cells*

Electricity consumption	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
Subsidy	-.0776753	.0279223	-2.78	0.012	-.135920	-.0194305
Number of Solar cells	-.0177076	.0072639	-2.44	0.024	-.033	-.0025553
Population	.3596893	.090309	3.98	0.001	.1713079	.5480706
GDP	-.0311051	.0178714	-1.74	0.097	-.068	.006174
Electricity supply	-.0020992	.001573	-1.33	0.197	-.005380	.0011821
Electricity price	-.0002251	.0000642	-3.51	0.002	-.000359	-.0000912
year						
2018	.0199603	.0086597	2.30	0.032	.0018964	.0380242
2019	.0331474	.0132394	2.50	0.021	.0055305	.0607643
2020	.0430894	.0155155	2.78	0.012	.0107247	.075454
2021	.063363	.0196878	3.22	0.004	.0222949	.1044311
2022	0	(omitted)				
2023	0	(omitted)				
_cons	15.91729	1.02475	15.53	0.000	13.7797	18.05488

When the number of solar cell installations is included as a potential mediating variable Number of solar cells, the effect of Subsidy becomes statistically significant (-0.0777, p < 0.05). This means that the removal of the subsidy affects electricity consumption indirectly, via a reduced number of installations. Number of solar cells is also negative and significant (0.0177, p < 0.05), which means that the more installations are made, the lower the electricity consumption. This strengthens the hypothesis that households that invest in solar cells reduce their purchased electricity thanks to self production. Electricity price is strongly significant (-0.00023, $p < 0.01$), which indicates that the price of electricity continues to have an important role as a driving force behind changes in consumption.

Significant impact on households' energy behavior, but through investment decisions rather than through a direct impact on consumption. It also explains why the direct effect in Table 2 was not significant, the full effect is only realized when investments are taken into account.

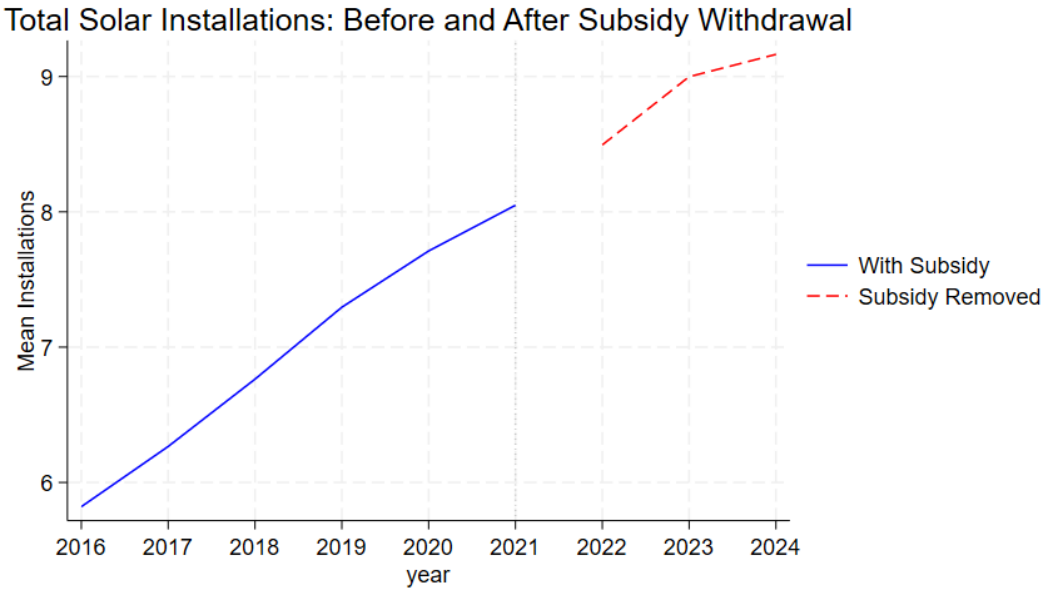
Table 6: *Indirect effect via capacity (Solar cells capacity)*

Electricity consumption	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
Subsidy	-.031125	.0177614	-1.75	0.095	-.068	.0059246
Solar cell capacity	-.0055349	.0041925	-1.32	0.202	-.014	.0032106
Population	.3892952	.0935757	4.16	0.000	.1940997	.5844908
GDP	-.033317	.0171383	-1.94	0.066	-.07	.0024328
Electricity supply	-.0014863	.0011322	-1.31	0.204	-.003848	.0008755
Electricity price	-.0000992	.0000457	-2.17	0.042	-.00019	-3.85e-06
year						
2018	.0074322	.0063472	1.17	0.255	-.00580	.0206723
2019	.0129173	.0087254	1.48	0.154	-.00528	.0311181
2020	.0197979	.0107238	1.85	0.080	-.002571	.0421673
2021	.0315917	.0130285	2.42	0.025	.0044147	.0587686
2022	0	(omitted)				
2023	0	(omitted)				
_cons	15.43748	1.065309	14.49	0.000	13.21528	17.65968

In Table 4 an alternative channel is examined, the installed solar capacity (solar cell capacity). Subsidy is negative and weakly significant (-0.0311, $p < 0.1$), suggesting some indirect effect also via capacity rather than number. However solar cell capacity itself is nog significant, suggesting that the amount of capacity does not in itself explain changes in electricity consumption. A possible interpretation is that larger installations do not necessarily lead to proportionally lower electricity consumption from the grid, for example due to low efficiency, lack of storage or that households with large systems also tend to consume more. Electricity price remains significant and negative (-0.00010, $p < 0.05$), confirming that price is an important variable for understanding consumption behavior.

5.4 Direct effects of the subsidy on solar energy use

***Figure 1**: Installations before and after*



The graph shows the average annual development of the number of solar cell installations (Number of Solar cells) in the treatment and control groups. During the period 2016-2020, for example, before the policy change, both groups followed closely parallel trends, indicating that they developed at a similar rate. This parallelism strengthens the confidence that the observed difference after 2021 can be interpreted as a result of the policy intervention, rather than underlying structural differences between the groups.

After 2021, a clear deviation in the trend is visible. While the overall installation rate continued to grow prior to the policy change, the trend flattened or even declined following the removal of the subsidy. This suggests that the loss of investment support had a negative effect on households' propensity to invest in solar cell technology. This graphical pattern aligns with the regression results, where the Subsidy variable is negative and statistically significant for both the number of installations and installed capacity.

6. Discussion

The role of subsidies in household investment

The most most clear and robust results in the study show that government subsidies have a strong impact on households' propensity to invest in solar cells. Both Table 1 and 3 report highly significant negative coefficients for the variable Subsidy 8-3.798*** and -0.0777**, respectively). This means that the removal of the investment subsidy has lead to a significant decrease in both the installation rate and electricity reduction, providing empirical support for the theory that financial incentives affect private investments in climate friendly technologies. The results are in line with previous research by De Groote and Verboven (2019), who argues that household investment decisions are sensitive to financial incentives, especially when it come to high initial costs. Karlsson (2024) emphasizes that subsidies that reduce the payback period on investments are crucial in lowering the threshold for technology adoption. The fact that investments decrease sharply after the subsidy is withdrawn strengthens the hypothesis of a subsidy effect. This is in line with the litterature on subsidy effect.

Direct and indirect effects on electricity consumption

The other central question in the study concerns the extent to which subsidies affect households' own electricity consumption. As shown in Table 2, Subsidy shows a negative but not significant effect on electricity consumption (-0.0074; p = 0.121), indicating that the removal of the subsidy itself did not change electricity consumption in the short term. This is not surprising, as the subsidy did not directly affect the price of electricity, but rather investments in its own production. However, the picture changes when installations are included as a mediating variable. In Table 3, the model shows that Subsidy has a significant negative effect (0.0777**) and that Number of solar cells is also significantly negative (-0.0177**), indicating that investments in solar cells indirectly affect households' dependence on the electricity grid. This confirms the theory that investments in own production change consumption behavior, an example of how technology investments can generate secondary environmental benefits through changed habits. Interestingly, Table 4, where installed capacity is used as a mediating variable, shows a weaker and non-significant effect. This suggests that it is the decision to install, and not the size of the installation, that changes household behavior. A possible explanation is that the impact of capacity is more heterogeneous and dependent on behavioral factors such as electricity habits, storage solutions, and energy efficiency.

Considerations and robustness

The combination of Fixed effects panel data analysis and a Difference-in-Differences design. The Fixed Effects model controls for all time invariant differences between municipalities, such as climate, culture, or infrastructure, while DiD captures the average change after the policy intervention. This dual method helps to increase internal validity and strengthens causal interpretations. The results are also strengthened by robustness checks in the form of graphs that support the assumption of parallel trends. The graphical analyses clearly show that the treatment and control groups followed similar patterns before the removal of the subsidy, which is a central premise of the DiD model. The fourth graph shows a sharp trend break after 2021, which is particularly convincing as visual evidence. At the same time, there are some methodological limitations. For example, it is possible that other concurrent policy changes or external factors (such as rising electricity prices or changed media coverage) also influenced the results. Although the model controls for electricity prices and GDP, other unknown time-varying factors may have played a role. In addition, the measurement of solar cell capacity and number of installations is at an aggregate level, which does not capture the microbehavior of households in detail.

Policy implications

The results clearly show that investment subsidies are an effective policy instrument for driving technology adaptation in the household sector. The abolition of the subsidy resulted in significantly reduced investments, which suggests that many households are marginally willing to invest without financial incentives. The study also shows that these investments in turn affect household electricity consumption, which means that subsidies not only have a technical effect but also a behavioral effect. Thus, subsidies are not only a matter of technology diffusion, but also of energy behavior and consumption patterns.

The study emphasizes the importance of considering indirect effects in policy evaluation. If one only looks at the direct effect of subsidies on electricity consumption (Table 2), one can incorrectly conclude that the subsidy is ineffective. Only when the investment chain is considered (look at tables 3 and 4) does the effect become clear. This underlines the importance of designing policy evaluations that capture both economic, technical but also behavioral impacts.

6.1 Limitations

Measurement uncertainty and proxy variables

Several of the key variables used in the study, such as the Number of solar cells and Solar cell capacity, may create a measurement error or lags in the data reporting. This is particularly true during the transition period around the abolition of the subsidy in 2021. The binary indicator Subsidy (Investment subsidy for solar cells) captures a policy change, but does not accurately reflect how support levels, application rates or distribution of funds varied between regions. This means that the treatment intensity is not fully reflected in the analysis, which potentially leads to an underestimated effect for this report.

Limited data

Due to limited availability of publicy accessible data, this study only analyses the data from 2016-2023. The policy under this analysis came into force in 2009, and the available panel data extends to 2023. The analysis, therefore, primarily captures short-term effects of the reform. As investments in solar cell systems are capital-intensive and are often preceded by long decision-making and installation processes, there is reason to assume that some effects have not yet been realized within the analysis period. For example, changes in electricity consumption as a result of newly installed systems may only become apparent after several years. Therefore, the results of this study should be interpreted as an initial indication of the reform’s impact, rather than a comprehensive long-term evaluation.

7. Conclusion

The purpose of this study was to investigate the effect of government investment subsidies for solar cells systems on household investments in and use of renewable energy in Sweden. By applying a quantitative method with a Fixed Effects panel model that's combined with a Difference-in-Differences design (DiD), the study was able to identify both direct and indirect effects of the reform that involved the phasing out of the investment subsidy.

The results clearly shows that the subsidy have had a strong positive impact on the number of solar cell installations and the total installed capacity. When the subsidy was abolished, there was a statistically significant decrease in both the number of installations and installed capacity. On average, the number of new solar cell installations per county decreased by approximately 3.8 units per year after the subsidy Investeringsstöd för solceller) was removed. Given that some counties previously had in the order of 10-15 new installations per year, this represents a decline of up to 25-35%. This is a clear indication that the subsidy functioned as a powerful economic incentive structure.
These results reinforce previous research that has shown households' high implicit discount rate and thus the need for financial support for investments in solar cell technology to be perceived as profitable (De Groote & Verboven, 2019; Karlsson, 2024). They are also in line with international experience from, for example Germany, where subsidy systems have played a crucial role in technology adoption and market development.

Regarding electricity consumption, the analysis shows that the direct effect of the subsidy on household electricity use was not statistically significant. the effect was negative but too small to be reliably distinguished from chance. However, the model shows that when the number of installations is included as a mediating variable, the effect becomes clearly significant. A decrease in the number of installations, caused by the loss of the subsidies, in turn leads to increase in electricity use from the electricity grid. More specifically, the analysis shows that each additional solar cell installation reduces the households' purchased electricity by average of 1.77%, confirming that investments in own production led to reduced dependence on external energy sources.

The capacity variable (installed power), however, did not have the same clear effect on electricity use. the results suggests that it is primarily the decision to invest, rather than the size of the installation, that influences behavior. A possible interpretation is that households that invest in solar cells simultaneously change their consumption habits, for example by optimizing electricity use for self-produced electricity or by becoming more aware of energy savings.

The study's robustness checks support the causal conclusions. The graphical analysis of installation trends before and after the reform clearly shows parallel trends between the treatment and control groups before the subsidy abolition, as well as a sharp trend break afterwards – in line with the quantitative results.

From a policy analysis perspective, the study contributes important insights. First, it shows that investment subsidies are an effective policy instrument for promoting technology diffusion in the household sector. Second, the results emphasize that these investments in turn have important secondary effects, through reduced electricity consumption and changed energy behavior. The total effect on electricity use will therefore only be visible if both the direct and indirect mechanisms are included in the analysis. A narrow interpretation of only consumption data, as in e.g. Table 2, therefore risks underestimating the real effect of the reform.

As a finalized conclusion it shows that state investment support for solar cell systems has not only contributed to an increased installation rate but also to changes in energy behavior. The quantitative results show that the abolition of the subsidy has meant concrete declines in investments and thus also in household self-sufficiency in electricity. The results underline the need to include both technical and behavioral effects in evaluations of climate policy instruments. In the long run, the study contributes to the understanding of how economic incentives can shape both markets and everyday behavior. It points to the importance of well-designed, long-term, and socially inclusive energy policy measures.

8. Future research

For future research, it would be valuable to complement this quantitative analysis with some qualitative studies on why some households refrain from investing even when subsidized, and how households that install solar cells use the technology. In addition, micro-level analyses (individual households) could provide even more accurate insights into consumption patterns, investment logic, and the practical effect of the technology. It would also be interesting to investigate combined policy instruments, such as subsidies together with information campaigns, energy taxes, or feed-in tariffs, similar to the models that Andersson (2019) discusses. Such a combination could potentially further enhance the effect by reducing both economic and psychological barriers.

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Appendix

Figure 2 to 4 shows the rate 2016 to 2021, where the blue and red lines is very close or almost exactly the same as each other. This means that both groups have the same growth pattern before the treatment.

Figure 2: *Solar capacity*

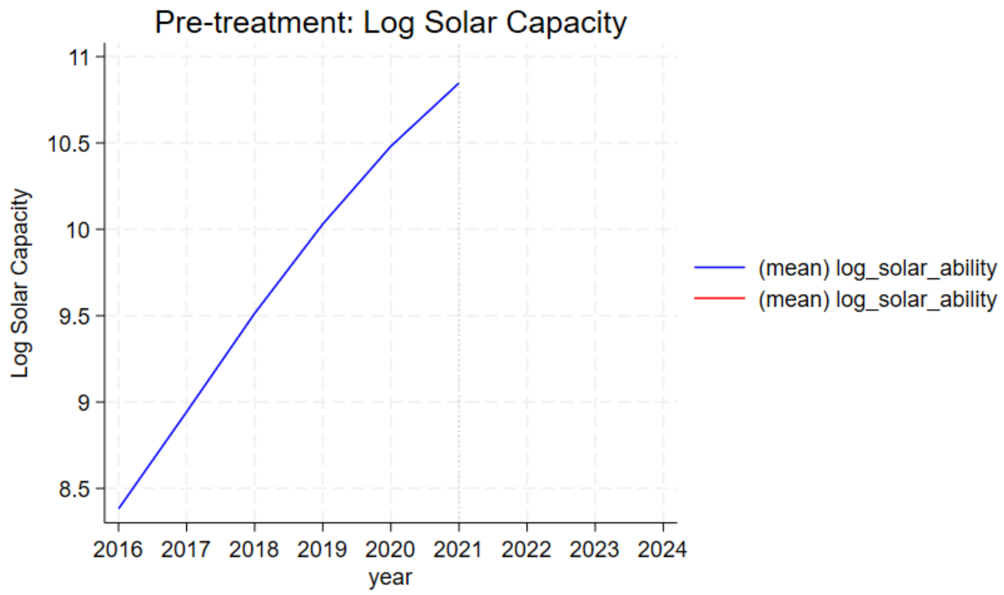


Figure 3*: Electricity consumption*

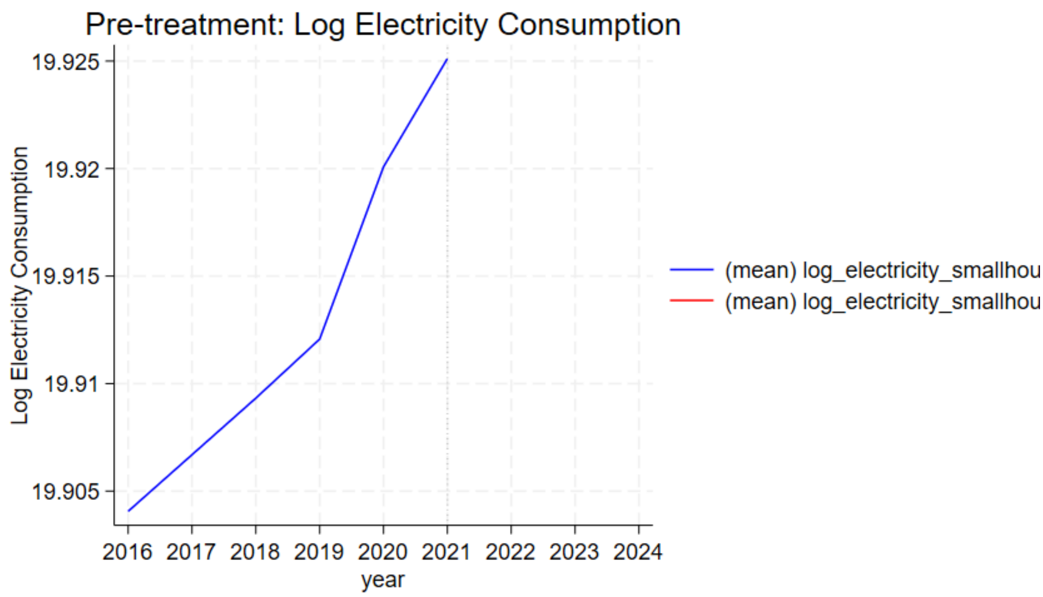
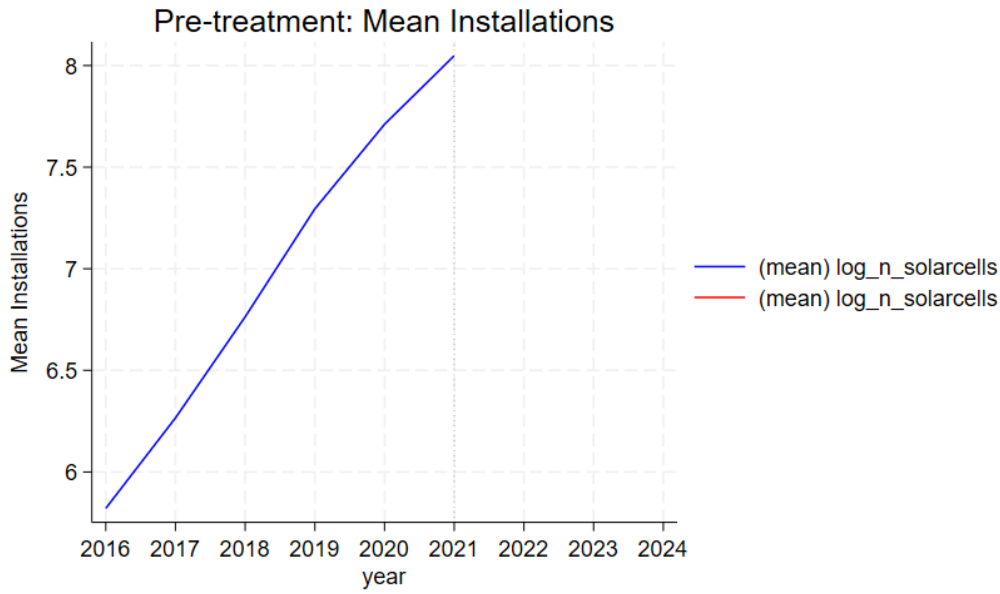


Figure 4: *Installations*



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