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DO GREEN USERS BECOME GREEN VOTERS?

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ABSTRACT

We estimate the causal effect of the diffusion of solar photovoltaic (PV) systems on the fraction of Green Party votes in federal and state elections in Baden-Württemberg, Germany. Our estimates are based on instruments that induce exogenous variation in roof appropriateness to PV installation. We find that PV adoption had a strong positive effect on Green Party votes. The effect is connected to the direct engagement of households with the PV system and does not reflect reciprocity to economic gains from PV. Our estimates likely reveal changing attitudes towards environmentally friendly values after adopting PV produced by cognitive dissonance.

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The historic challenge of climate change requires economies to change from fossil to non-fossil sources of energy within a short horizon. So far, governments and supra-national organizations have relied heavily on economic incentives such as green tax rebates, price subsidies for green energy production and cap-and-trade schemes to reduce the use of fossil fuels; however, based on the limited impact that economic incentives are having,[1] it is becoming increasingly clear that a more comprehensive strategy will be necessary to meet this challenge.

A lever that has often been overlooked by governments is the implementation of policies that change citizens' attitudes towards green values.[2] Improving attitudes towards the environment would help in fighting climate change as environmentally conscious citizens undertake actions and support policies that favor an energetic transition. Additionally, firms adopt environmentally friendly production processes to please these pro-green consumers, as has recently been shown by Aghion et al. (2023).

Despite their potential, a key difficulty faced by policies that attempt to shape citizens' attitudes towards the environment is that we know little about what drives these attitudes. This paper intends to start closing this important gap by exploring one hypothesis about the drivers of pro-green attitudes.

Our research question is whether there is a causal effect of adopting solar photovoltaic (PV) panels on pro-green attitudes manifested as an increase in political support for the Green Party. To explore this question, we assemble a municipal-level dataset of PV diffusion and share of Green Party votes in federal and state (Laender) -level elections in Baden-Württemberg, Germany between 1996 and 2021. To ensure that our estimates reflect the causal effect of exogenous changes in PV adoption, we construct instruments based on the appropriateness of roofs in each municipality for the installation of PV systems using exogenous physical properties of the roofs, such as their orientation (North-South vs. East-West) and inclination. Our estimates show that the adoption of PV systems caused an increase in the share of the vote won by the Green Party. This effect is quantitatively significant and could account for the entire

[1]For example, Cullen (2013) estimates a low elasticity of wind power installations with respect to subsidies. Murray et al. (2014) show that production and investment tax credits for renewable electricity and tax credits for the production and use of biofuels have had a very limited impact on the emissions of greenhouse gases in the US. De Groote and Verboven (2019) show that consumers apply a very high discount rate to future revenues from selling green electricity to the grid, limiting the impact of feed-in tariffs on PV adoption.

[2]The notion that a government might try to affect the values of its citizens may be questionable on moral or even legal grounds. A prior consensus would be needed to collectively embrace those values and explicitly recognize them in a general law or the constitution.

increase in green votes between the late 1990s and 2021 in federal elections, and for more than half of that increase in regional elections. Furthermore, these findings are relevant beyond Baden-Württemberg, as we observe a similar reduced-form relationship between solar adoption and changes in attitudes towards the Green Party at the individual-level in other German regions, based on the Socio-Economic Panel (SOEP, 2022).

To understand the mechanism responsible for this effect, we study how the relationship between PV adoption and green votes depends on (i) the size of a PV installation, (ii) whether a household owns or rents the dwelling where a solar energy system is installed, and (iii) the feed-in tariffs paid to households that sell their green electricity to the grid. Our analysis indicates that the effect of PV adoption on green votes is entirely driven by household systems in resident-owned dwellings and that it is not larger in periods where feed-in tariffs were higher.[3] These observations suggest that being directly involved in the installation and maintenance of a PV system induces households to change their attitudes towards green values, not in response to an economic gain, but to derive greater utility from their environmentally-friendly actions. In this way, our findings are a manifestation of cognitive dissonance (Festinger, 1957).

The role of cognitive dissonance in political attitudes is an under-studied research area. One exception is Mullainathan and Washington (2009), who find that the act of voting for a candidate leads to a more favorable opinion of that candidate in the future. More generally, our investigation is also related to studies on the drivers of voting behavior. Deacon and Shapiro (1975) and Fischel (1979) use survey data from voters in referenda on environmental issues to study which factors affect the probability of voting in support of the environment. They find that occupation, political affiliation, education, income and location are important drivers of green voting.[4] Schumacher (2014) considers similar factors and reaches similar conclusions with respect to Green Party voting in Germany. Our analysis controls for these drivers of voting behavior to identify the independent effect of adopting green energy systems on Green Party voting. Finally, the literature on policy feedbacks (i.e. reverse causality)[5] has argued

[3]This is consistent with evidence that monetary rewards do not affect voting patterns(Cornelius, 2004; Wang and Kurzman, 2007; Schaffer and Schedler, 2007).

[4]Related studies (e.g., Tjernström and Tietenberg (2008), Torgler and García-Valiñas (2007), Whitehead (1991), Nord et al. (1998) and Zelezny et al. (2000)) use survey data to study the relationship between socio-economic and demographic variables and green attitudes.

[5]See Schattschneider (1935), Pierson (1993) and Soss and Schram (2007).

that new policies can create their own support through a range of mechanisms. The effects we identify are orthogonal to potential policy feedbacks since we exploit exogenous variation in adoption rates. Furthermore, the fact that some green policies can foster green attitudes is a powerful mechanism that governments may actively use to accelerate the transition to green energy paradigm.

The rest of this paper is organized as follows. Section I describes the Baden-Württemberg data. Section II presents the specification, the instrumentation strategy, and the estimates of the causal relationship between PV adoption and green votes. In this section, we also present robustness checks using household-level data from SOEP (2022) and discuss the mechanism driving the estimated effect of solar energy adoption and change in Green Party support. Section III concludes with some policy implications of our findings.

I Data

We study the relationship between PV adoption and green values at two different levels of aggregation. First, we analyze the relationship at the municipal level (Local Administrative Unit 2, LAU-2), examining the approximately 1100 municipalities in Baden-Württemberg (Figure 1), one of Germany's 16 federal states, located in the southeast of the country. We then gain additional insights on the role of various mechanisms by exploring household-level data from the German Socio-Economic Panel (SOEP, 2022), a representative longitudinal survey administered to approximately 30,000 individuals in 11,000 households.

The analysis relies mostly on three variables: support for the Green Party in elections and household surveys (our dependent variable), the adoption of PV systems (the independent variable), and, in the case of Baden-Württemberg, the appropriateness of roofs for the installation of PVs in each municipality (which is the basis for the instrument). Next, we describe the construction of these measures and their patterns for Baden-Württemberg. We will describe the equivalent measures in our household survey data in Section II.B.[6]

[6] See Online Appendix A for details on the regional data and Online Appendix B for details on the survey data.

A Green Votes

We use electoral results at the municipal level from all federal and state elections from 1996 until 2021.[7] The share of votes in Baden-Württemberg for the Green Party increased from 9.2 percent in 1998 to 17.1 percent in 2021 in federal elections and from 12.1 percent in 1996 to 32.6 percent in state-level elections. Underneath this aggregate trend, there has been considerable heterogeneity in the evolution of support for the Green Party, as seen in Figure 1 Panels A and B, which plot the change in the share of green votes in each municipality for federal and state-level elections.

B Diffusion of PV Systems

The level of PV diffusion in municipality r, $F_{r,t}$, is measured by the number of PV installations through time t, normalized to the number of residential buildings in the municipality. Since 2000, photovoltaic systems have diffused significantly throughout Baden-Württemberg, and across Germany (see Figure 1 Panel C and Figures A.4 and A.5 in the Online Appendix). The fraction of residential buildings with a PV system in Baden-Württemberg increased from 0.04 percent in 1999 to 16.8 percent in 2020. This increase coincided with the approval of the Renewable Energy Sources Act in 2000, which raised the feed-in tariff for electricity generated from PV systems.[8]

Underneath the general increase in the diffusion of PV systems, there is significant geographic variation. Figure 1 Panel C displays a map of Baden-Württemberg with the increase in PV diffusion between 1995 and 2020 in each municipality. The largest increases occurred in the southeast while the smallest occurred in the northwest.

In our analysis, we do not rely on the long-run relationship between green votes and PV diffusion to identify the effect of PV diffusion on green votes because other factors may spuriously affect the long-run relationship between these variables. These factors are absorbed by time dummies and a full set of municipal fixed effects (interacted with type of election). Our identification strategy relies on the association across municipalities and over time between the instrumented change in PV diffusion and the

[7]The number of second votes is normalized to the number of valid votes. Details are available in Online Appendix A.1.
[8]We describe the evolution of the feed-in tariff in Online Appendix A.2.

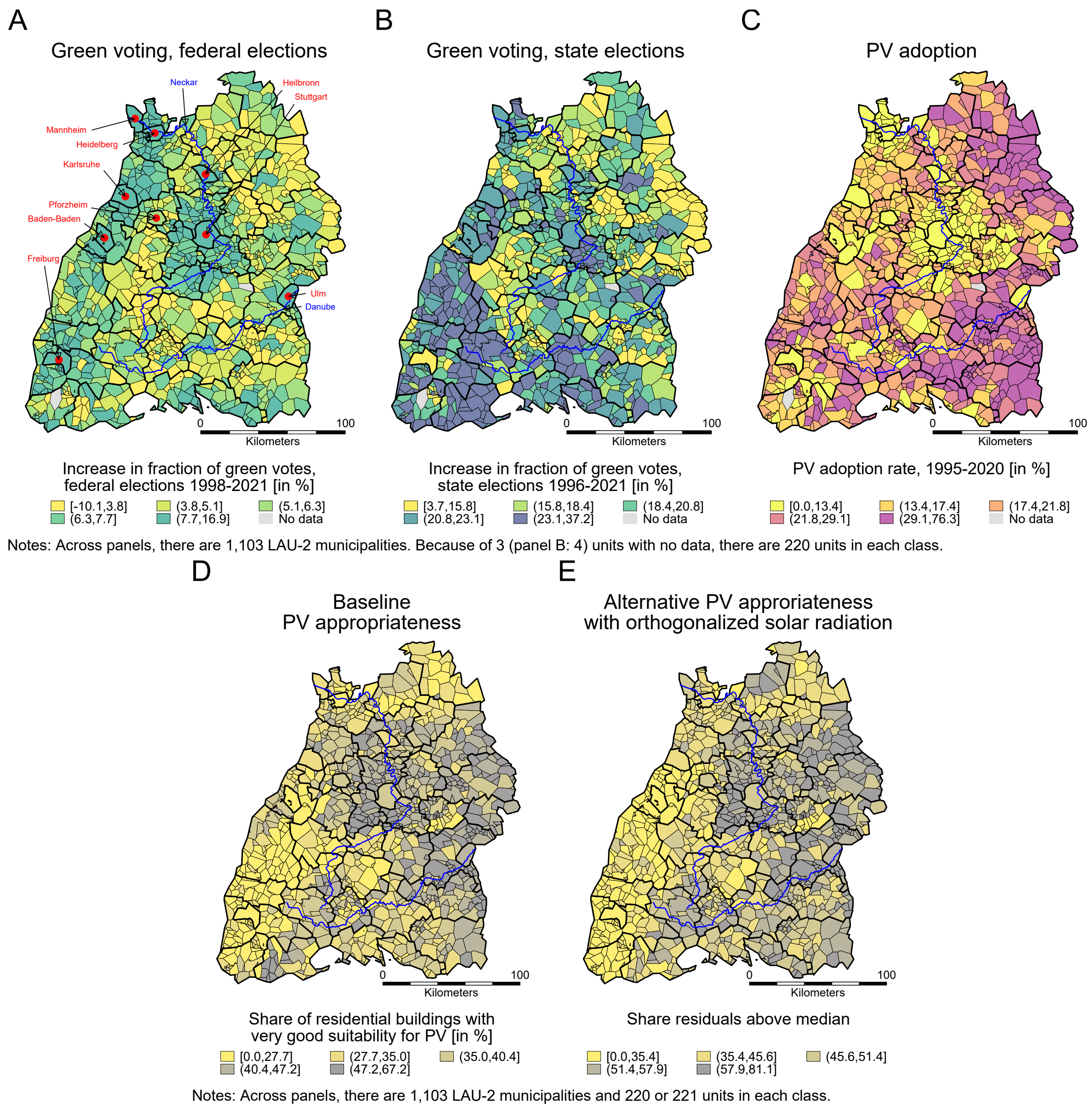

Figure 1: From left to right, the increase in the fraction of green votes in federal elections (1998-2021) and in state elections (1996-2021), the increase in the PV adoption rate (1995-2020), a baseline measure of PV appropriateness, and an alternative PV appropriateness measure with orthogonalized solar radiation for Baden-Württemberg on LAU-2 level.

Notes: Germany has 16 federal states (NUTS-1: Nomenclature des unites territoriales statistiques). Baden-Württemberg is one of the federal states in Germany. LAU-2 (Local Administrative Unit) municipalities are the smallest administrative unit in Germany. Because NUTS-3 districts and LAU-2 municipalities are constantly restructured, we do not have voting data for every single unit; we do, however, have data for the vast majority of them. We analyze data on green voting for the six landtag elections between 1996 and 2021, the seven federal elections between 1998 and 2021, and the yearly PV adoption for 1,099 (99.5 percent) LAU-2 municipalities in Baden-Württemberg. Maps are in Gauss-Krüger zone 3 projection (EPSG: 31467).

change in green votes. Critical to the construction of instruments for PV adoption are exogenous factors that determine the appropriateness of roofs for the installation of PV systems, which we will discuss next.

C Roof Appropriateness

Various roof and location characteristics determine the suitability of a building for a PV installation by changing the potential energy that a PV system can generate. These include solar radiation, roof orientation, inclination, altitude above sea level, shadowing, and roof size (see Online Appendix A.3). To the extent that (i) Green support across municipalities is orthogonal to these physical factors, (ii) that these factors are uncorrelated with potential drivers of green support (such as income or education), and (iii) that roof appropriateness is an important driver of PV adoption, measures of roof appropriateness are a valid instrument for PV adoption. Before discussing the details of how we constructed the appropriateness measures, we can check condition (ii) by computing the correlation between average income per capita (proxied by municipal income taxes per capita) and solar radiation and altitude across municipalities. We find that income and solar radiation are uncorrelated (0.03) while income and altitude are negatively correlated (-0.19). This suggests that instruments of PV adoption based on physical determinants of roof appropriateness will, in principle, satisfy the exogeneity requirement.

The State Office for the Environment, Measurement and Nature Conservation of Baden-Württemberg (LUBW, 2016) conducted an aerial roof census that collected high-resolution data (i.e., at the building level) on the determinants of roof appropriateness and computed the solar energy potential of each residential building. Our baseline appropriateness measure is the share of residential buildings in each municipality that have a solar energy potential between 95 and 100 percent of the maximum solar radiation.[9] (See panel D of Figure 1.)

In addition to this baseline measure, we consider two alternative measures of roof appropriateness constructed using subsets of the determinants of roof appropriateness in the baseline. Arguably, the physical dimensions captured by the alternative measures of appropriateness are the most exogenous

[9]LUBW (2016) uses the best suited roof area in the building to compute solar energy potential.

of all the determinants of appropriateness. Therefore, by showing the robustness of our estimates to using these alternative instruments, we should gain further assurance of the causal interpretation of the estimated association between PV adoption and Green support. The first alternative measure filters solar radiation from the baseline measure. We do so by regressing building-specific solar energy potential on the solar radiation in the one-square-kilometer area where the building is located.[10] We then use the residuals from this regression to construct a measure of roof appropriateness in a municipality that reflects the fraction of buildings in a municipality where residual solar energy potential is above the median residual in Baden-Württemberg.

Additionally, we consider measures of roof appropriateness that are exclusively based on roof orientation information. Orientation is an important driver of the energy generation potential of a roof. In Western Europe, the optimal orientation is to the south. A roof oriented to the east with an inclination of 37 degrees produces a quarter less electricity than a roof with the same inclination oriented to the south. Importantly, roof orientation largely depends on factors that are completely orthogonal to green sentiment, such as the direction in which a road or a river cuts a town (see Online Appendix A.3.3). Both its relevance and exogeneity make roof-orientation an ideal variable to construct instruments for PV adoption. We construct two different measures of municipal roof appropriateness based on information on roof orientation. The first, which reflects the extensive margin, consists in the fraction of residential buildings in a location with a deviation from the optimal orientation smaller than 30 degrees. The second, which captures the intensive margin, is the average deviation from optimal orientation among the buildings with a deviation of more than 30 degrees from the optimal orientation.[11]

It is worth noting that there is significant variation in all three measures of roof appropriateness across the municipalities of Baden-Württemberg, as illustrated in Figure 1 Panels D and E and Figure A.10 (Online Appendix).

[10] See Table A.3, Online Appendix.

[11] Because solar panels on flat roofs can be oriented in any direction, we consider flat roofs to have a southward orientation.

II Econometric analysis

A Econometric Model and Estimates

We hypothesize the following empirical relationship between green votes and the diffusion of PV systems:

$$V_{e,r,t} = \alpha_{0,e,r} + \alpha_{1,r} * t + \widetilde{\delta}_t + \beta * F_{r,t-1} + \widetilde{u}_{e,r,t}, \tag{1}$$

where $V_{e,r,t}$ is the fraction of green votes cast in LAU-2 municipality r, in election $e \in \{\text{Federal, State}\}$, in year t, and $F_{r,t-1}$ is the fraction of residential buildings in municipality r that have installed a PV system in year $t-1$. The coefficient β reflects the effect of PV diffusion on green votes which we are interested in estimating. To examine this relationship in the data, we take time-differences in the left and right sides of (1) across consecutive elections of a given kind (i.e., federal or state-level) to obtain the equation:

$$\triangle V_{e,r,t} = \alpha_{1,r} + \delta_t + \beta * \triangle F_{r,t-1} + u_{e,r,t}, \tag{2}$$

where $\triangle V_{e,r,t} = V_{e,r,t} - V_{e,r,t-k}$, with k being the number of years between elections, $\triangle F_{r,t-1} = F_{r,t-1} - F_{r,t-k-1}$ is the PV adoption rate in r between $t-k-1$ and $t-1$ and x_t denotes $\widetilde{x}_t - \widetilde{x}_{t-k}$.

OLS estimates of β in (2) may be biased by the omission of other relevant drivers of changes in green votes that may be correlated with PV adoption or by reverse causation. To obtain unbiased estimates of β, we instrument $\triangle F_{r,t-1}$ using exogenous municipal variation in roof appropriateness, as we explain next.

First, consider the realistic assumption that the diffusion of PV systems through municipality r approximately follows the logistic function:

$$F_{r,t} = \frac{a' * A_r}{1 + e^{-b*(t-c)}}, \tag{3}$$

where b is the speed of diffusion, c is the inflection point, and the ceiling $a' * A_r$ is determined by a vector of factors, A_r, some of which are endogenous to local Green attitudes while others are exogenous (both to Green attitudes and to other factors that may be correlated with Green attitudes, such as income).

Approximating $\triangle F_{r,t}$ with the time derivative of $F_{r,t}$, we obtain:

$$\triangle F_{r,t} \cong \frac{dF_{r,t}}{dt} = \frac{be^{b(t-c)}}{1+e^{-b(t-c)}} F_{r,t} = bF_{r,t} - b\frac{F_{r,t}^2}{a' * A_r}. \tag{4}$$

Expression (4) motivates the following strategy to construct instruments for $\triangle F_{r,t}$. (i) Estimate the diffusion curve using a subset of the exogenous drivers of the ceiling to proxy for A_r. (ii) With the estimates of a', b and c, construct the lagged predicted diffusion level, $\widehat{F}_{r,t}$. (iii) Instrument $\triangle F_{r,t-1}$ by $\widehat{F}_{r,t-k-1}$ and $\widehat{F}^2_{r,t-k-1}$.

The intuition behind this instrumentation strategy is simple. Exogenous variation in roof-appropriateness induces differences in the long-run diffusion of PV systems across municipalities. Since diffusion approximately follows a logistic pattern, this exogenous variation in the ceilings induces exogenous variation in the entire diffusion path. Consequently, exogenous drivers of roof-appropriateness also induce exogenous variation in the increase in the diffusion of PVs, the adoption rate.

By construction, our instruments are exogenous, as they consist of interactions of exogenous variables and non-linear functions of time. Additionally, they are relevant if the logistic curve is a good approximation to the municipal diffusion of PV and the exogenous drivers capture some of the cross-municipal variation in the ceiling diffusion level.

We implement this instrumentation strategy by estimating the diffusion process for PVs and then using these estimates to construct lagged predicted diffusion level (and its square). We use those predictions as instruments of the lagged adoption rate in (2). The first column of Table 1 reports the estimates of the PV diffusion model. As anticipated, the logistic curve fits the diffusion of PV systems at the municipal level very well. We precisely estimate the speed of diffusion and inflection point parameters, and obtain a significant positive estimate of the effect of the baseline roof appropriateness measure on the ceiling (a_1). The second column of Table 1 reports the estimates from the first stage regression where we instrument the adoption rate of PVs by the lagged level of predicted diffusion and its square.[12] As implied by equation (4), the coefficient on the lagged predicted diffusion is positive while the quadratic effect is negative. Both are significant at the 1 percent level, and the F-statistic for the test of joint significance of

[12]To capture other fixed drivers of PVs as well as time-varying factors that are common across municipalities, we include municipal fixed effects (which can potentially vary across election types) and time fixed effects.

Table 1: Instrument variable estimation of increase in share of green votes on increase in PV diffusion for Baden-Württemberg (weighted by eligible voters) for federal and state elections.

	Diffusion Model	IV		Alternat. appropriateness	
		1st stage	2nd stage	Orthogonal. Solar Rad.	Roof Orientation
	(1)	(2)	(3)	(4)	(5)
	$F_{\text{PV},t-1}$	$\Delta F_{\text{PV},t-1}$	$\Delta V_{e,t}$	$\Delta V_{e,t}$	$\Delta V_{e,t}$
Predicted PV adoption rate: $\Delta\hat{F}_{\text{PV},t-1}$			0.83	0.91	0.47
			(0.35)	(0.44)	(0.19)
Lagged, predicted instrument: $\hat{F}_{\text{PV},t-k-1}$		0.87			
		(0.21)			
Lagged, predicted instrument squared: $\left(\hat{F}_{\text{PV},t-k-1}\right)^2$		-0.02			
		(0.01)			
Constant: α		-0.70	0.24	0.03	1.25
		(0.88)	(1.00)	(1.25)	(0.55)
Ceiling: a_0	12.47				
	(0.99)				
Ceiling (Baseline PV appropriateness): a_1	0.21				
	(0.03)				
Speed: b	0.41				
	(0.00)				
Inflexion point: c	30.70				
	(0.03)				
LAU-2 x Election-type fixed effects	No	Yes	Yes	Yes	Yes
Year x Election-type fixed effects	No	Yes	Yes	Yes	Yes
R^2	0.79	0.75	0.82	0.82	0.82
Adj. R^2	0.79	0.70	0.78	0.78	0.78
Final log-likelihood $\mathcal{L}$	-137176.1	-21256.4	-25869.0	-25868.7	-25871.3
F		14.5	5.5	4.2	5.9
$F_{a_1=0}$ | $F^{\text{1st stage}}_{\hat{F}_{\text{PV},t-k-1},\hat{F}^2_{\text{PV},t-k-1}=0}$ (p-value)	56.5 (0.00)		14.5 (0.00)	15.4 (0.00)	29.7 (0.00)
N	46158	12085	12085	12085	12085

Notes: Across columns, we analyze the LAU-2 level in the federal state of Baden-Württemberg, Germany (for 1,099 LAU-2 municipalities r) and several points in time. In column (1), we include the 42 years t between 1980 and 2021. In columns (2-5), we focus on 11 points in time (state or federal election e in year t): six with federal elections (2021, 2017, 2013, 2009, 2005, and 2002, along with 1998, due to differencing) and five with state elections (2021, 2016, 2011, 2006, and 2001, along with 1996, due to differencing). Column (1) shows the estimates of the Diffusion Model (equation (3)) with non-linear least squares. a_0 and a_1 affect the diffusion ceiling, b the speed and c the inflexion point. a_1 is the coefficient for the baseline PV appropriateness, which is the share of residential buildings with very good appropriateness for PV. Column (2) presents the first stage (2SLS) estimates with the lagged, predicted instrument and the lagged, predicted instrument squared. The lagged instrument is predicted according to the Diffusion Model from column (1). Column (3) shows the second stage estimates (2SLS) of the increase in green votes on the predicted PV adoption rate (from column (2)). Columns (4) and (5) show alternative second stage estimates (2SLS) of the increase in green votes on the predicted PV adoption rate. Column (4) is based on a Diffusion Model in which alternative PV appropriateness with orthogonalized solar radiation affects the ceiling. Table C.3 in the Online Appendix includes the Diffusion Model, the first stage, and further details. Column (5) is based on a Diffusion Model in which alternative PV appropriateness based on roof orientation only affects the ceiling. Table C.4 in the Online Appendix includes the Diffusion Model, the first stage and further details. Columns (2)-(5) are weighted by the number of eligible voters at election e in year t. Table C.1 (Online Appendix) contains the descriptive statistics corresponding to this table. SE adjusted for clustering on LAU-2 level in parentheses.

the instruments is 14.5, considerably greater than the conventional threshold of 10 used to establish the strength of the instruments. Column (3) reports the estimates of the second stage regression. That is, the point estimate of β in (2) after instrumenting the PV adoption rate $(\triangle F_{r,t-1})$. We find a strong, positive and significant effect of PV adoption on the increase in the share of valid votes casted for the Green Party in a municipality.

Robustness

We next explore the robustness of the estimated effect of PV adoption on green votes along two dimensions. First, we re-estimate (2) using less comprehensive measures of roof-appropriateness as instruments of PV adoption. Second, we consider other specifications of the reduced-form relationship between green votes and PV diffusion in (1) that allow for non-linearities, heterogeneous effects across elections, and effects on green votes from the adoption of PV systems in neighboring municipalities.

Columns (4) and (5) of Table 1 present estimates of β corresponding to the alternative instruments. In Column (4), we use the instrument that is orthogonal to solar radiation; in Column (5), we use the instruments that are based exclusively on roof orientation. The estimated values of β are positive and significantly different from zero, and are in the same ballpark as the estimate obtained with the baseline measure of appropriateness in Column (3).[13]

Column (1) of Table 2 explores the presence of non-linearities in the relationship between PV adoption and green votes by including the quadratic of the PV diffusion level in a municipality in (1).[14] The coefficient of the quadratic term is zero, and its inclusion has no impact on the point estimate of the linear effect captured by β. Column (2) explores whether the relationship varies between federal and state elections, finding no significant difference, though the point estimate of β is smaller in state elections. Third, we explore whether Green sentiment is driven by the adoption of PVs in a given municipality or in its neighbors. The latter could be consistent with a positive estimate of β if there is spatial correla-

[13]The values of the F-statistics for the first-stage regressions indicate that the alternative instruments are also strong. (See Table 1.)

[14]This leads to the following version of Equation (2):

$$\triangle V_{e,r,t} = \alpha_{1,r} + \delta_t + \beta * \triangle F_{r,t-1} + \gamma * F_{r,t-1} * \triangle F_{r,t-1} + u_{e,r,t} \tag{5}$$

tion in both PV adoption and roof appropriateness. To disentangle these two hypotheses, we construct the average predicted (lagged) adoption rate among neighboring municipalities $\left(\triangle\widehat{F}_{PV,t-k-1}^{Neighbors}\right)$ for each location.[15] Column (3) of Table 2 reports the instrumented effects on the change in green vote shares of both the local and the neighbors' PV adoption rates. We find that only the adoption rate in the municipality affects the share of green votes, and that the magnitude of the coefficient is robust to controlling for the average PV adoption rate in the neighboring towns.

Magnitude

Having established the existence and robustness of a statistically significant causal relationship between PV diffusion and green votes, we explore the magnitude of the estimated effect. To get a sense of whether the estimated effect is large or small, we combine the estimates of β together with either the actual or predicted increases in the share of buildings with PV systems. The resulting magnitudes can be interpreted as the increase in the share of green votes induced by our channel if the causal estimates of β we have identified from short-run variation in PV adoption prevailed in the long-run. This condition is not generally warranted[16] and therefore one should take the calculations with caution. However, we believe that they provide a sense of of the quantitatively significance of our channel.

As a reference, the actual increase in green votes in Baden-Württemberg from the last election in the 1990s until 2021 was 7.8 percentage points in federal elections and 20.4 percentage points in state elections (see Table C.15, Online Appendix). The increase in green votes implied by our econometric model falls in between these two magnitudes. Using the baseline roof appropriateness measure as an instrument, the implied increase in green votes is 12.9 percentage points when using the actual increase in PV systems and 16.3 percentage points when using the predicted increases in PV systems. With the estimates from the two alternative instruments, we obtain similar magnitudes for this effect. Therefore, our estimates imply that the diffusion of PV systems lead to an important increase in the share of green votes.

[15]By neighboring we mean that they share a municipal border. This approach is similar to Comin et al. (2012).

[16]However, in Table 4 we show that the estimates of β do not diminish over time.

Table 2: Second stage instrument variable estimates of increase in share of green votes on increase in PV diffusion for Baden-Württemberg (weighted by eligible voters) for federal and state elections.

	Alternative specifications			PV system size			Other technologies	
	Quadratic	By election	Spatial cor.	Household		Industrial	Wind	Biogas
	(1) $\Delta V_{e,t}$	(2) $\Delta V_{e,t}$	(3) $\Delta V_{e,t}$	(4) $\Delta V_{e,t}$	(5) $\Delta V_{e,t}$	(6) $\Delta V_{e,t}$	(7) $\Delta V_{e,t}$	(8) $\Delta V_{e,t}$
Predicted PV adoption rate:								
$\Delta \hat{F}_{\mathrm{PV},t-1}$	0.80	1.04	1.24					
	(0.37)	(0.47)	(0.49)					
Pred. adopt. rate interacted:								
$\Delta \hat{F}_{\mathrm{PV},t-1} \times \hat{F}_{\mathrm{PV},t-k-1}/100$	0.43							
	(0.47)							
StateElection $\times \Delta \hat{F}_{\mathrm{PV},t-1}$		-0.42						
		(0.44)						
Pred. adopt. rate of neighbors:								
$\Delta \hat{F}^{\mathrm{Neighbors}}_{\mathrm{PV},t-1}$			-0.66					
			(0.86)					
Predicted adoption rates:								
$\Delta \hat{F}^{\leq 10\mathrm{kW}_p}_{\mathrm{PV},t-1}$				1.62				
				(0.76)				
$\Delta \hat{F}^{\leq 30\mathrm{kW}_p}_{\mathrm{PV},t-1}$					0.93			
					(0.41)			
$\Delta \hat{F}^{\geq 100\mathrm{kW}_p}_{\mathrm{PV},t-1}$						-2.40		
						(1.08)		
$\Delta \hat{F}_{\mathrm{Wind},t-1}$							74.69	
							(52.28)	
$\Delta \hat{F}_{\mathrm{Biogas},t-1}$								37.92
								(23.89)
Constant	0.14	0.16	0.94	-0.45	0.18	6.30	2.40	2.08
	(0.95)	(1.03)	(1.64)	(1.42)	(1.06)	(1.68)	(0.13)	(0.32)
LAU-2 x Election-type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year x Election-type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
Adj. R^2	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Final log-likelihood $\mathcal{L}$	-25868.3	-25867.6	-25821.5	-25876.8	-25870.2	-25600.1	-25888.5	-25883.9
F	5.7	2.8	4.7	4.6	5.2	4.9	2.0	2.5
$\mathrm{F}^{\mathrm{1st\ stage}}_{\hat{F}_{\mathrm{PV,t\text{-}k\text{-}1}}, \hat{F}^2_{\mathrm{PV,t\text{-}k\text{-}1}}=0}$ (p-value)	14.5 (0.00)	14.5 (0.00)	14.5 (0.00)	10.7 (0.00)	14.2 (0.00)	1.2 (0.30)	3.8 (0.02)	5.6 (0.00)
N	12085	12085	12067	12085	12085	11964	12085	12085

Notes: Across columns, we analyze the LAU-2 level in the federal state of Baden-Württemberg, Germany (for 1,099 LAU-2 municipalities r) and several points in time. Across columns, we focus on 11 points in time (state or federal election e in year t): six with federal elections (2021, 2017, 2013, 2009, 2005, and 2002, along with 1998, due to differencing) and five with state elections (2021, 2016, 2011, 2006, and 2001, along with 1996, due to differencing). Across columns, we show second stage estimates. The following tables include the corresponding Diffusion Model, the first stage and further details: for columns (1-3), see Table 1; for column (4), see Table C.16 (Online Appendix); for column (5), see Table C.17 (Online Appendix); for column (6), see Table C.19 (Online Appendix); for column (7), see Table C.20 (Online Appendix); for column (8), see Table C.22 (Online Appendix). In column (3), $\Delta \hat{F}^{\mathrm{Neighbors}}_{\mathrm{PV},t-1}$ is the average predicted adoption rate in municipalities that share a border with municipality r. In this regression, we lose some observations because we focus on the balanced panel. SE adjusted for clustering on LAU-2 level in parentheses.

B Understanding the Mechanism

In the rest of this paper, we will explore the mechanism by which PV diffusion affects green votes. First, we study the variation in the relationship between PV adoption and green votes across household vs. industrial energy systems and between home-owners vs. renters to study the relevance of the household's direct involvement in the adoption of a PV system for the adoption to change the household's preferences for the Green Party. Second, we explore the "votes for money" hypothesis by which PV adopters reward the Green Party for increases in feed-in tariffs by voting for it. Based on our findings, we propose what we see as the most plausible mechanism.

Household vs. Industrial Systems

We use the installed capacity and energy source to classify of each system as household or industrial. We consider two cut-offs for household PV systems: 10 and 30 kilowatt-peak $\left(\mathrm{kW_p}\right)$. Alternatively, we use a conservative minimum threshold of 100 $\mathrm{kW_p}$ of installed capacity for industrial PV systems.[17] Columns (4) through (6) of Table 2 show the estimates of the instrumented effect of municipal PV adoption on the change in the share of green votes for each of these three classes of PV systems. We further extend the analysis to the installation of industrial facilities that produce green energy using wind turbines (Column 7) and biogas (Column 8).[18] Our key findings are that the effect of PV diffusion on green votes is entirely driven by the diffusion of household systems, and that, in contrast to household systems, the installation of industrial systems (PV, wind or biomass) in a municipality is not associated with an increase in green votes.

Owned vs. Rental Dwellings

Next, we turn our attention to household survey data to gain further insights on the mechanism behind the effect of PV adoption on Green Party votes. The Socio-Economic Panel (SOEP) is a representative household survey that (among other topics) inquires about the political party supported by an individual and the intensity of their support. We use this information to construct a binary measure of increase in

[17]We use solar radiation to measure the appropriateness for industrial PV. Online Appendices A.4 and C.3.1 contain details.

[18]We use the wind power potential to measure the appropriateness for wind power and solar radiation for biogas. Online Appendices A.5 and C.3.1 contain details.

support for the Green Party, $\Delta Green_t$, which equals one if an individual states a change in support from another party to the Green Party or if they states an increase in the intensity of support for the Green Party between years $t-1$ and t. $\Delta Green_t$ is zero in all other cases.

Since 2007, the SOEP has included a question about whether households live in dwellings with solar energy systems.[19] Using this information, we construct two independent variables. The first, $Solar_{t-1}$, measures whether the household had a solar energy system installed in its dwelling in year $t-1$. The second, $\Delta Solar_{(t-3:t-1)}$, measures whether a household did not have a solar system at $t-4$ and adopted one between $t-3$ and $t-1$.[20]

The first exercise we conduct with SOEP is to examine whether the patterns uncovered across the municipalities of Baden-Württemberg also hold nationally at the household level. To this end, we run logit regressions of $\Delta Green_t$ on $Solar_{t-1}$ and $\Delta Solar_{(t-3:t-1)}$ across households. In contrast to the Baden-Württemberg data, we do not have roof-appropriateness information to instrument solar adoption here; however we can partially capture other drivers of green sentiment by controlling for real household income. The point estimates are reported in the first two columns in Panel A of Table 3. Despite differences in geography and levels of aggregation, these estimates confirm that a household's adoption of a solar energy system is positively associated with an increase in its support for the Green Party. Next, we take advantage of the information in SOEP about whether a household owns or rents the unit where it lives to explore whether the association between the adoption of a solar system and support for the Green Party differs by ownership status. In the balanced sample, approximately 60 percent of the observations correspond to home owners while the rest are renters. Columns (3) through (6) in Panel A of Table 3 show that, while for home owners there is a strong positive association between the adoption of a solar system support for the Green Party, there is no association for non-home owners. Therefore, owning the dwelling where the solar system is installed is a critical part of the mechanism that causes the observed increase in support for the Green Party after installing a solar energy system.

The granularity of SOEP can be used to better understand the timing of solar energy system adoption and changes in household support for the Green Party. To this end, we define the variables $\Delta Solar_t$,

[19] Online Appendix B contains details.

[20] Here, we focus on a balanced sample of households. In Online Appendix C.3.2, we replicate the analysis for the unbalanced panel obtaining similar results.

Table 3: Logit coefficient estimates for Socio-Economic Panel, which is a representative longitudinal survey.

Panel A: Estimates of solar level and solar change on change in green attitude	All		Home owners		Non-home owners	
	(1) $\Delta Green_t$	(2) $\Delta Green_t$	(3) $\Delta Green_t$	(4) $\Delta Green_t$	(5) $\Delta Green_t$	(6) $\Delta Green_t$
$Solar_{t-1}$	0.42		0.51		-0.18	
	(0.13)		(0.14)		(0.54)	
$\Delta Solar_{t-3:t-1}$		0.44		0.56		-0.15
		(0.19)		(0.19)		(0.96)
$\ln$ (Real Income$_t$)	0.13		0.13		0.19	
	(0.07)		(0.11)		(0.11)	
$\Delta \ln$ (Real Income$_t$)		-0.13		-0.48		0.24
		(0.10)		(0.12)		(0.15)
N	57,933	53,599	32,478	28,992	21,714	20,882
# individuals	4,930	4,567	3,288	2,978	2,508	2,384
# households	3,573	3,342	2,224	2,032	2,020	1,931
DF_M	191	187	174	169	154	152
Final log-likelihood $\mathcal{L}$	-7006.8	-6433.8	-4152.2	-3561.8	-2733.1	-2744.6

Panel B: Reverse causality: Estimates of level and change in green attitude on solar change	All		Home owners		Non-home owners	
	(1) $\Delta Solar_t$	(2) $\Delta Solar_t$	(3) $\Delta Solar_t$	(4) $\Delta Solar_t$	(5) $\Delta Solar_t$	(6) $\Delta Solar_t$
$Green_{t-1}$	-0.04		0.11		-0.42	
	(0.22)		(0.26)		(0.42)	
$\Delta Green_{t-3:t-1}$		0.28		0.35		0.11
		(0.16)		(0.20)		(0.30)
$\ln$ (Real Income$_t$)	0.86		0.46		1.40	
	(0.12)		(0.18)		(0.21)	
$\Delta \ln$ (Real Income$_t$)		0.12		-0.00		0.47
		(0.24)		(0.29)		(0.42)
N	36,423	36,143	18,084	17,978	9,589	9,490
# individuals	4,540	4,539	2,899	2,897	2,106	2,100
# households	3,296	3,293	1,920	1,914	1,689	1,682
DF_M	107	104	86	83	65	62
Final log-likelihood $\mathcal{L}$	-1775.9	-1832.1	-1183.8	-1203.7	-488.1	-526.9

Notes: We study the years 2020 through 2009 (along with 2008 and 2007, due to differencing). In columns (1), (3) and (5), we include time$*$NUTS-1, college, vocational degree and labor status dummies and control for age. In columns (2), (4) and (6), we include time$*$NUTS-1 and dummies for changes in college, in vocational degree and in labor status. We only examine those who did not have a solar system in 2007. Table C.23 in the Online Appendix contains the corresponding descriptive statistics. SE adjusted for clustering on household level in parentheses.

$Green_{t-1}$ and $\Delta Green_{(t-3:t-1)}$. $\Delta Solar_t$ is a binary variable equal to 1 if the individual lived in a dwelling where a solar system has been installed between year $t-1$ and t; it is 0 otherwise. $Green_{t-1}$ is equal to 1 if the respondent claims to support the Green Party in year $t-1$, and is 0 otherwise. $\Delta Green_{(t-3:t-1)}$ is 1 if the individual moved to support the Green Party or if they increased the strength of their support for the Green Party over the previous three years, and 0 otherwise.

We use these variables to estimate logit regressions of $\Delta Solar_t$ on $Green_{t-1}$ and $\Delta Green_{(t-3:t-1)}$, controlling for either log of real household income at $t-1$ or the growth in real income from $t-1$ to t. In columns (1), (3) and (5) of Panel B of Table 3 we see that Green Party supporters are not more likely to adopt solar systems than those who do not support the Green Party. Columns (2), (4) and (6) of Panel B of Table 3 illustrate that individuals who became greener were not more likely to install solar energy systems than those who did not become greener in a previous three-year period. These findings suggest that greater Green support does not increase the likelihood of adopting solar energy systems. Therefore, the German household survey data is consistent with the direction of causation identified by our instrumented regressions with the municipality data from Baden-Württemberg.

Votes for Money

The Green Party was the key proponent of the new, non-retroactive, feed-in tariff scheme, EEG, that came into effect in 2000.[21] The impact that this policy had on the income of PV adopters raises the possibility that the increase in votes for the Green Party may be how grateful PV adopters reciprocate for the greater tariffs. To explore this "votes for money" hypothesis, we first compute the magnitude of the economic gains of installing a PV system and discuss whether they are significant enough to change voting behavior. Afterwards, we study the timing of feed-in tariffs under the new regime and explore whether the effect of PV adoption on green votes changed over time alongside with the feed-in tariffs.

Given the time-series variation in the feed-in tariff and installation costs over the period 2000-2020, we calculate the present discounted value of income net of installation and maintenance costs from a PV system (relative to the total disposable household income during the useful life of the system) in four systems that vary by installed capacity and solar radiation (full load hours). These cases correspond to

[21] Non-retroactive means that changes in the scheme only affected new PV installations.

the median and 90th percentile of each variable.[22] The profit-to-income ratio ranges from -1.9 percent to 2 percent, with the highest values in the years around 2010 and in systems with higher capacity and full-load hours. These magnitudes suggest that, even for high-capacity systems installed in areas with high solar radiation, the net revenues from PV electricity production were modest. Given the evidence that voters are insensitive to monetary rewards (Cornelius, 2004; Wang and Kurzman, 2007; Schaffer and Schedler, 2007), it seems unlikely that new PV adopters rewarded the Green Party for the net income they received from new PV system with their votes.

Under the EEG scheme, the rate for PV electricity sold back to the grid went from 0.1 euros per KWh to 0.5 per KWh in 2000, remaining around that level until 2010 (see Figure A.3, Online Appendix). In 2010, the feed-in tariffs started a steep, but gradual, decline until they reached a level of 0.15 euro per KWh in 2013. Since then, they have declined even further, to a price of 0.1 euros per KWh. The direct effects of these changes in feed-in tariffs on PV diffusion are absorbed by the time dummies and, therefore, do not affect the estimates of the impact of PV diffusion on green votes in the Baden-Württemberg and SOEP datasets. It might be the case, though, that feed-in tariffs differentially affected voting behavior across regions and that these changes in behavior were correlated with the exogenous component of the adoption rate. To rule this possibility out, we re-estimate our regressions, both for Baden-Württemberg and for the SOEP, allowing for a differential effect of PV and solar energy adoption rates on Green Party votes and support in periods with high feed-in tariffs and PV profitability.[23] Table 4 presents the results. The main finding is that we do not see a higher effect of PV adoption on green votes in periods with high feed-in tariffs and profitability. Indeed, in most specifications, the effect is significantly lower during these periods. This finding, together with the small magnitude of the potential economic profits from adopting PV systems, strongly suggests that the causal effect of PV adoption on green votes is not a manifestation of a "votes for money" effect.

[22] See Online Appendix C.3.3.

[23] See Online Appendix C.3.4 for details.

Table 4: Controlling for profitability for Baden-Württemberg (columns (1-3)) and for home owners in the Socio-Economic Panel (columns (4-7)).

	2nd stage OLS (for Baden-Württ.)			Logit coeff. estimates (home owners, SOEP)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	$\Delta V_{e,t}$	$\Delta V_{e,t}$	$\Delta V_{e,t}$	$\Delta Green_t$	$\Delta Green_t$	$\Delta Green_t$	$\Delta Green_t$
Predicted PV adoption rate: $\Delta\hat{F}_{\text{PV},t-1}$	0.83	0.93	1.75				
	(0.35)	(0.36)	(0.46)				
$\text{Dummy}_{\text{Before 2012}} \times \Delta\hat{F}_{\text{PV},t-1}$		-2.54					
		(0.55)					
$\text{Dummy}_{\text{High PV profits}} \times \Delta\hat{F}_{\text{PV},t-1}$			-2.44				
			(0.36)				
Household PV Profitability:							
$\frac{\Delta p_{\text{PV,t-1}}}{p_{\text{PV,t-k-1}}} *$ (Solar radiation / 1000)	0.67						
	(0.87)						
$Solar_{t-1}$				0.44		0.49	
				(0.14)		(0.14)	
$Solar_{t-1} \times \text{Dummy}_{\text{Before 2012}}$				0.31			
				(0.19)			
$Solar_{t-1} \times \text{Dummy}_{\text{High PV profits}}$						0.08	
						(0.18)	
$\Delta Solar_{t-3:t-1}$					0.62		0.74
					(0.21)		(0.21)
$\Delta Solar_{t-3:t-1} \times \text{Dummy}_{\text{Before 2012}}$					-0.29		
					(0.42)		
$\Delta Solar_{t-3:t-1} \times \text{Dummy}_{\text{High PV profits}}$							-0.67
							(0.39)
$\text{Dummy}_{\text{Before 2012}}$				-1.19	-1.71		
				(0.37)	(0.52)		
$\text{Dummy}_{\text{High PV profits}}$						-1.13	-1.70
						(0.38)	(0.52)
Constant: α	0.00	0.04	-0.99	-3.45	-2.57	-3.47	-2.57
	(1.10)	(1.02)	(1.14)	(0.94)	(0.24)	(0.94)	(0.24)
LAU-2 x Election-type fixed effects	Yes	Yes	Yes				
Year x Election-type fixed effects	Yes	Yes	Yes				
R^2	0.82	0.82	0.82				
Adj. R^2	0.78	0.78	0.78				
Final log-likelihood $\mathcal{L}$	-25868.5	-25838.3	-25802.7	-4150.9	-3561.4	-4152.1	-3559.9
F	2.8	11.2	28.0				
$\text{F}^{\text{1st stage}}_{\hat{F}_{\text{PV},t-k-1},\hat{F}^2_{\text{PV},t-k-1}=0}$ (p-value)	14.5 (0.00)	14.5 (0.00)	14.5 (0.00)				
N	12085	12085	12085	32478	28992	32478	28992
# individuals				3,288	2,978	3,288	2,978
# households				2,224	2,032	2,224	2,032
DF_{M}	2	2	2	175	170	175	170

Notes: In columns (1)-(3), we analyze the LAU-2 level in the federal state of Baden-Württemberg, Germany (for 1,099 LAU-2 municipalities r) and several points in time. Across columns, we focus on 11 points in time (state or federal election e in year t): six with federal elections (2021, 2017, 2013, 2009, 2005, and 2002, along with 1998, due to differencing) and five with state elections (2021, 2016, 2011, 2006, and 2001, along with 1996, due to differencing). For the first stage estimates in column (1), we use the lagged predicted instrument (and the lagged, predicted instrument squared) from the Diffusion Model from Table 1, column (1). In columns (1)-(3), we show second stage estimates (2SLS) of the increase in green votes on the predicted PV adoption rate (from column (2), Table 1) and weight by the number of eligible voters in year t. In columns (1)-(3), we show SE adjusted for clustering on LAU-2 level in parentheses. In column (1), we control for the profitability of household PV systems (below 30kW$_p$), which has its median at 0, mean at 0.11, standard deviation at 1.31, minimum at -1.17, maximum at 6.75. In columns (4)-(7), we study home owners between the years 2020 through 2009 (along with 2008 and 2007, due to differencing) in the Socio-Economic Panel (in a balanced data set). In columns (4), and (6), we include time$*$NUTS-1, college, vocational degree and labor status dummies and control for age. In columns (5), and (7), we include time$*$NUTS-1 and dummies for changes in college, in vocational degree and in labor status. We only examine those who did not have a solar system in 2007. Table C.23 in the Online Appendix contains the corresponding descriptive statistics. In columns (4)-(7), we show SE adjusted for clustering on household level in parentheses.

Taking Stock

We have demonstrated the existence of a strong, positive causal effect of adopting PV systems on the share of votes for the Green Party. The effect is pretty immediate; in both municipal and household-level datasets, we observe an increase in green votes less than three years after PV adoption.

Direct involvement by households in the adoption and use of PV system appears important for this effect, based on the findings that (i) it is the municipal adoption of household systems, not the adoption of PV systems in neighboring municipalities, nor the adoption of industrial systems what drives the increase in Green Party votes, and (ii) the effect is driven by the households that own the dwellings where PV systems are installed, not by the households that rent them.

The effect is not driven by potential monetary gains from PV adoption because these gains are small, and the effect was not higher in periods where feed-in tariffs were high.

If monetary considerations are not a key channel, it must be the case that PV adoption directly changes the preferences of adopters towards green values. Why would that be the case? One possibility is that this effect is a manifestation of cognitive dissonance (Festinger, 1957), which causes agents to retroactively change their preferences or values in order to derive greater utility from their previous actions. In our context, this action is the adoption of a PV system. After adopting a PV system, agents derive a greater utility from adoption if they embrace green values, care more about the environment, and regard activities that contribute to preserving it more favorably.[24] The material manifestation of these new values is the observed increase in PV adopters' support for the Green Party.

III Conclusions

We have demonstrated that the adoption of PV systems causes an increase in the share of votes for the Green Party. This effect is unlikely to reflect a reciprocal, "votes for money" mechanism. Instead, it likely reflects a change in attitudes towards environmentally friendly values after adopting a solar energy system.

[24]See Comin and Rode (2013) for a model that precisely captures this mechanism.

The fact that engagement with green technology affects attitudes towards the environment to the point of affecting voting behavior has significant policy consequences. First, it shows that the diffusion of green technologies on climate change may have an overall impact that exceeds its direct effects — by inducing pro-environmental attitudes, adoption also prompts agents to embrace other behaviors that may lower greenhouse emissions. The change in green attitudes of consumers may further amplify the impact of public policies that foster green technology diffusion because firms engage in more pro-green behavior to please environmentally friendly consumers, as demonstrated by Aghion et al. (2023).

Second, our findings imply that the adoption of green energy by consumers may have a greater environmental impact than adoption by producers. Adoption by producers does not seem to induce green consumer attitudes; therefore, only adoption by consumers has an impact beyond its total installed capacity.

Third, the social desirability of the spread of green values, together with the effect of PV adoption on green attitudes and cross-sectional variation in geographic appropriateness for PV installation, could provide a rationale for using subsidies of consumer-oriented green technologies that vary negatively with the appropriateness of the technology.

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