

Analyzing solar PV installations: a catalyst or barrier to subsequent residential retrofits?

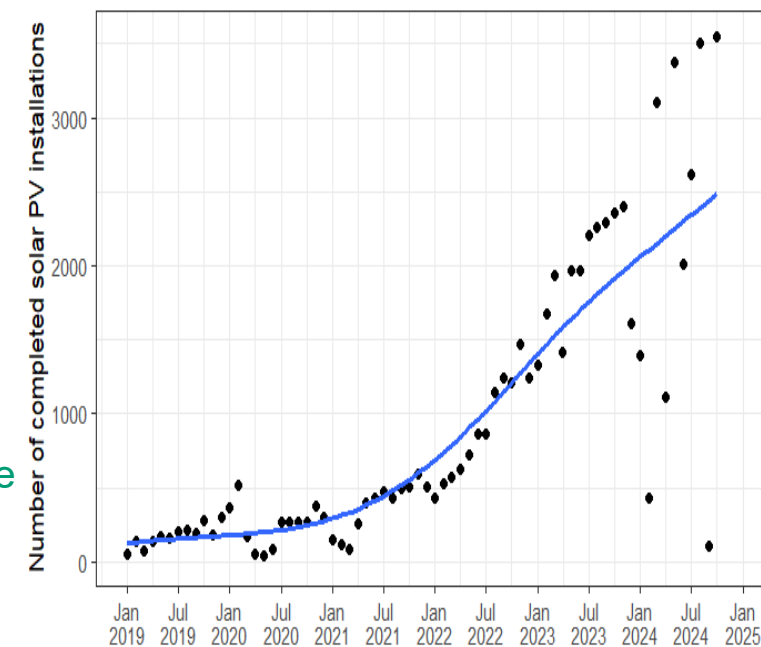
Unravelling the link between solar photovoltaic (PV) installations and future dwelling retrofits through statistical analysis

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Solar PV – background

- Solar PV
 - Solar PV installations are popular among homeowners (~65k applications).
 - Sharp increase in applications for Solar PV SEAI grant over the last three years
- Advantages of solar PV
 - Feed-in tariffs available in Ireland allowing for unused electricity fed back to the system & homeowner's electricity bill reduction
 - Presumably leads to further retrofit down the road (based on anecdotal evidence only)
 - **The aim of this research – investigate if data shows that solar PV installation is followed by additional retrofit. The hypothesis.**
- Disadvantages of solar PV
 - Gap between the solar PV generation and residential load curves.
 - Installation of solar PV does not change level of dwelling insulation (fabric U-value) even though it improves BER rating.
 - Potentially diverting homeowners' available funds away from measures that might be more effective (e.g., fabric first).

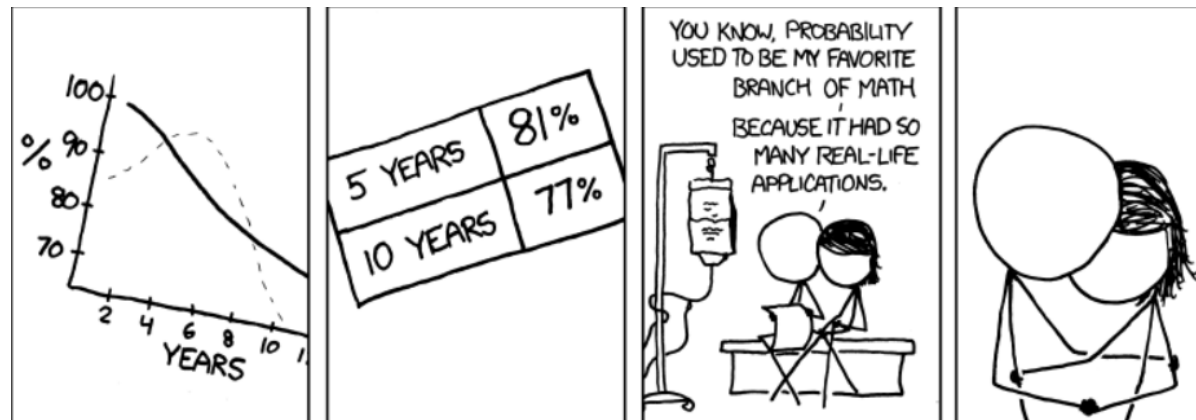


Is solar PV installation followed by additional retrofit? Precursors to analysis

- Available data
 - Solar PV database (since 2018)
 - Better Energy Homes database (since 2009)
 - Better Energy Communities
 - Deep Retrofit
 - One Stop Shop
 - BER database
- SEAI data allows for
 - Identify dwellings with solar PV installations that had another retrofit done
 - Identify dwellings with multiple retrofits
- Considerations
 - New-builds with PV are not included
 - Temporal relation of PV and other retrofits
 1. Solar PV is followed by retrofit
 2. Retrofit is followed by solar PV
 3. Both solar PV & retrofit at the same time
 4. Solar PV only, no other retrofit
- Counterfactual
 - Roof insulation is followed by another retrofit (~160k Roof insulation retrofits)
 - Heating controls is followed by another retrofit (~100k Heating Control retrofits)
- Reasons for choosing roof insulation and heating controls
 - Frequent retrofit measures
 - Suitable for most types of dwellings
 - Cheaper and can be considered as entry level retrofits

Methodology

- Statistical methods used for the analysis
 - Descriptive statistics
 - Chi-square tests
 - Survival analysis (Cox model, Random forest)



FORMULA

$$\chi^2 = \Sigma((O_i - E_i)^2 / E_i)$$

where:

χ^2 is the chi-square test statistic

O_i is the observed frequency for each category

E_i is the expected frequency for each category (based on the theoretical distribution)

Results - Descriptives

- Solar PV (grant is available for 6 years)
 - Total of 65,110 solar PV installs
 - Total of 1,362 solar PVs was followed by another retrofit
 - Total cost of retrofits amounted to 13 million Euro
 - On Average a solar PV installation results in additional € 200 in retrofits
- Roof insulation (only last 6 years used)
 - Total of 33,935 roof insulations completed
 - Total of 1,066 roof insulations was followed by another retrofit
 - Total cost of retrofits amounted to 11.9 million Euro
 - On Average an roof insulation results in additional € 350 in retrofits
- Heating controls (only last 6 years used)
 - Total of 24,225 heating controls completed
 - Total of 1,861 heating controls was followed by another retrofit
 - Total cost of retrofits amounted to 18 million Euro
 - On Average a heating controls installation results in additional € 740 in retrofits

Results – Chi-square tests

Measure-of-interest (PV/Roof/Controls) is followed by retrofit in next 2 years – 4 categories, last 2 years not included

	No, no retrofit	No, both at the same time	No, retrofit led to measure	Yes
Solar PV	87.2%	5.3%	4.3%	3.2%
Roof insulation	28.0%	65.0%	4.0%	3.0%
Heating controls	87.1%	7.6%	2.2%	3.1%

Measure-of-interest (PV/Roof/Controls) is followed by retrofit in next 2 years – 2 categories, last 2 years not included

	No vs. Yes (All data)		No, no retrofit vs. Yes (Partial data)	
	No	Yes	No	Yes
Solar PV	96.8%	3.2%	96.4%	3.6%
Roof insulation	97.0%	3.0%	90.4%	9.6%
Heating controls	96.9%	3.1%	96.6%	3.4%

- Chi-square tests
 - 4 categories: PV vs. Roof & PV vs Controls were significant
 - 2 categories: None significant except for PV vs. Roof in No vs. Yes (Partial data)
 - Main finding: PV is no more likely to be followed by other retrofit than roof insulation or heating controls

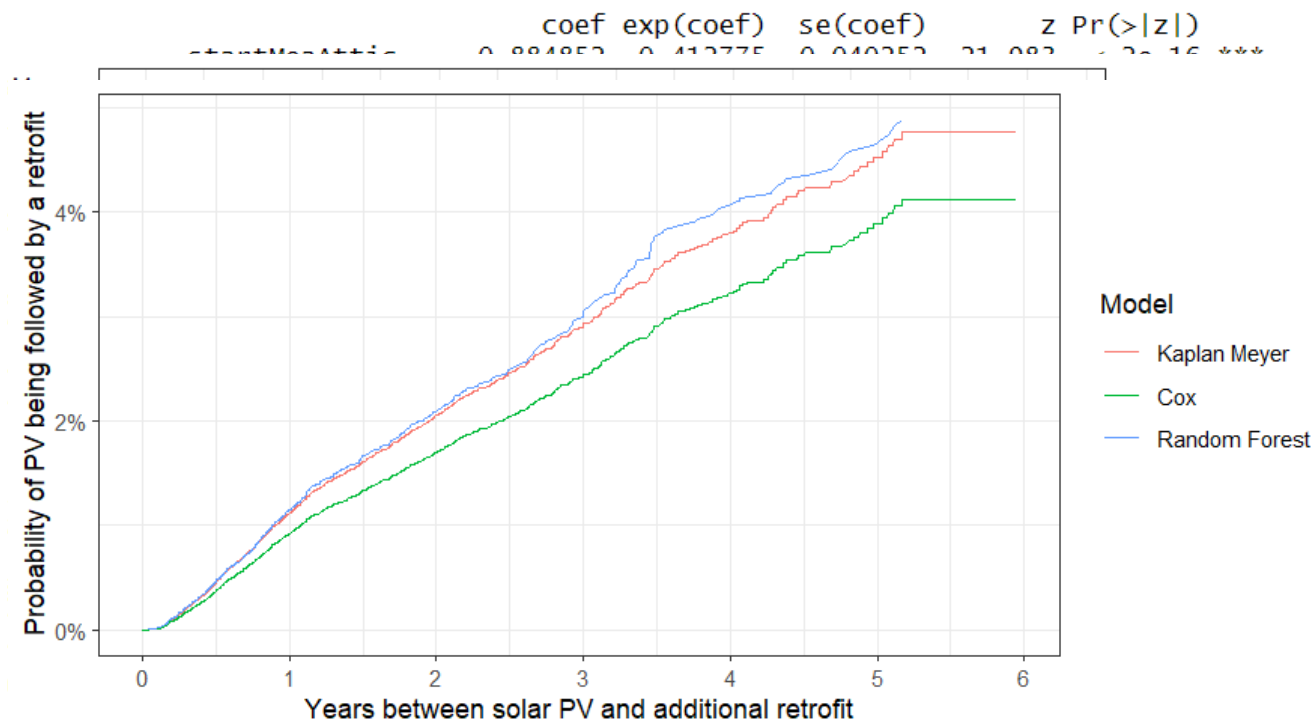
Survival analysis - Introduction

- Survival analysis mostly used in Medicine & Biology
 - Studies rates of death, organ failure, and the onset of various diseases – time until event
 - Here used to model probability of second retrofit application (time until event)
 - Useful for data where outcome is unknown due to time constraint – e.g., for recent PV applications we didn't observe yet if additional retrofit happened
- Survival analysis models used
 - Kaplan Meyer plot – Good to visualize probability of applications across time
 - Cox survival model (Semiparametric model)
 - Random forest (Machine learning algorithm)
- Covariates used
 - Measure-of-interest (Roof, Controls, **PV**)
 - BER (A, B, **C**, D, EFG, Unknown)
 - Dwelling size (log transformed)
 - Pobal HP Deprivation Index (cube transformed) by Small Area
 - Dwelling type (Apartment, Semi-detached/End-terraced, **Detached**, Mid-terraced)

Survival analysis – Results for “Yes” vs. “No” (All data)

n= 330680, number of events= 13726

- Kaplan Meyer plot
- Cox model
 - Solar PV is more likely to be followed by retrofit compared to roof insulation
 - Solar PV is less likely to be followed by retrofit compared to controls (small difference)
 - More affluent/advantaged neighbourhoods are more likely to apply for additional retrofits (negligible effect size)
 - Larger the house more likely to apply (negligible effect size)
 - Apartments and mid-terraced less likely to apply
 - Better BER rating more likely to apply

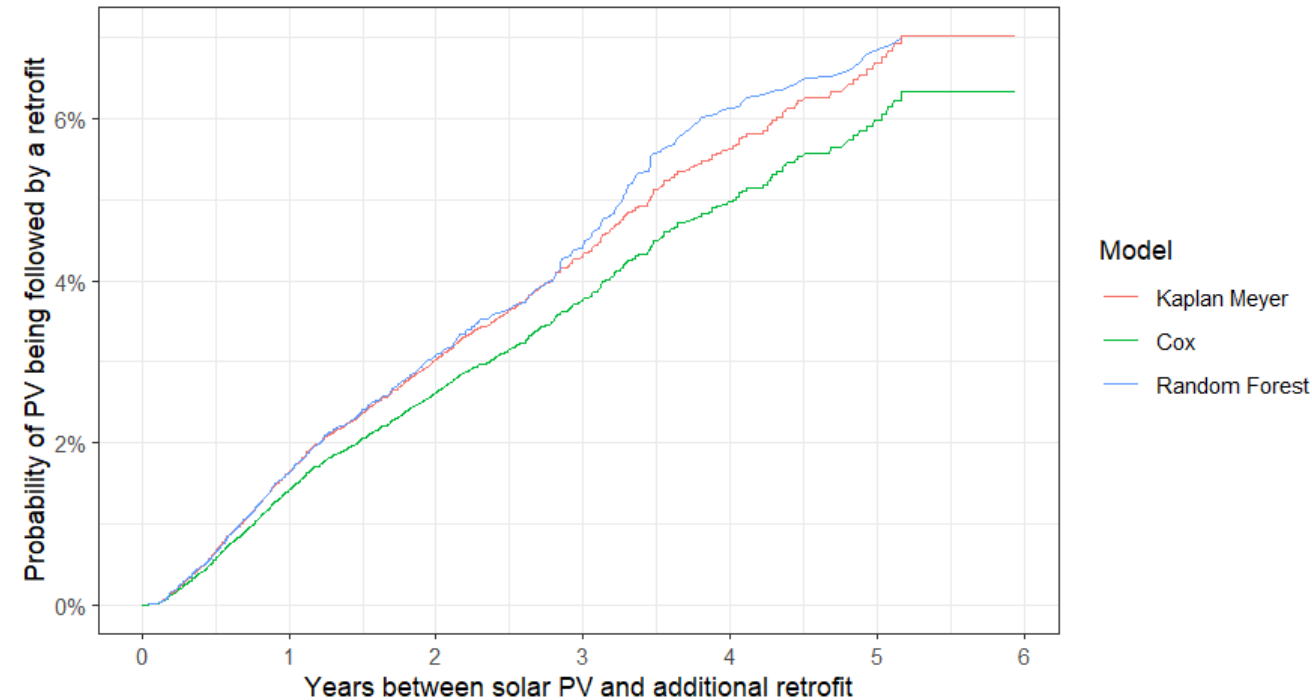


- Random Forest
 - Similar results to Cox model
 - Ranks covariates importance

Years between initial Measure and additional retrofit				
Variable	Importance			
Measuer-of-interest	0.0935	0.3601	2.5365	3.0409
BER	0.0207	0.5338	1.7965	1.9538
Dwelling type	0.0196	1.2261	0.7397	0.8994
Dwelling size	0.0152	0.8116	1.1587	1.3103
Deprivation index	0.0039			
		Likelihood ratio test= 14853 on 13 df, p=<2e-16		
		Wald test = 11188 on 13 df, p=<2e-16		
		Score (logrank) test = 14968 on 13 df, p=<2e-16		

Survival analysis – Results for “Yes” vs. “No, no retrofit” (Partial data)

- Kaplan Meyer plot
- Cox model
 - Solar PV is less likely to be followed by retrofit compared to heating controls and/or roof insulation
 - Apartments, mid-terraced and semi-detached are less likely to apply for additional retrofits
 - Better BER rating more likely to apply
- Random Forest
 - Similar results to Kaplan Meyer plot
 - Ranks covariates importance



Vari	POBL_X3	1.0000	0.9941	1.0001	1.0119
Measuer-of-inter	Dw_size_log	1.0806	0.9255	1.0224	1.1420
BER	DwSemi	0.8396	1.1910	0.8054	0.8753
Dwelling type	DwMid	0.5161	1.9375	0.4796	0.5555
Dwelling size	DwApt	0.3316	3.0160	0.2884	0.3812
Deprivation inde	DwUnknown_Dw	0.1161	8.6099	0.1022	0.1320
	BERA	3.9965	0.2502	3.6392	4.3889
	BERB	2.5008	0.3999	2.3969	2.6092
	BERD	0.6577	1.5205	0.6196	0.6981
	BEREFG	0.4889	2.0455	0.4430	0.5395
	BERUnknown_BER	1.2350	0.8097	1.1591	1.3159

Concordance= 0.666 (se = 0.003)
 Likelihood ratio test= 7494 on 13 df, p=<2e-16
 Wald test = 7191 on 13 df, p=<2e-16
 Score (logrank) test = 7884 on 13 df, p=<2e-16

Conclusion

- Solar PV does not result in higher likelihood of additional retrofit when compared to heating controls and or roof insulation
- The additional retrofit generated following solar PV is small and amounts to 1% -1,5% of yearly increment as predicted by Cox and Random forest models
- The level of concurrent retrofit is substantially higher than subsequent retrofit – especially for roof insulation.
- Effect of BER and dwelling type on subsequent retrofit
- Limitations
 - This research doesn't answer what drives additional retrofit
 - Makes assumptions that decisions to retrofit are taken just before application is made

Thank you