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Small-scale solar panel adoption by the non-residential sector: The effects of national and targeted policies in Australia

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Abstract

Use of solar photovoltaic (PV) panels by the non-residential sector can contribute to climate-change mitigation and boost economic outcomes. Prior studies have primarily focused on the residential sector. Using data from 1,595 postcodes across the Australian National Electricity Market, we investigate five novel research questions for non-residential solar-panel adoption. National and sectoral policies, business size, and cross-sectoral influences are found to be key drivers of non-residential solar PV uptake. We find a subsidy elasticity of about 1.2 for Australia's Small-scale Renewable Energy Scheme (SRES), an economy-wide renewable portfolio standard for small-scale renewables. Residential solar capacity is positively associated with future adoption by the local non-residential sector, and geographical convergence effects are observed. The findings align with the principle that investment is spurred by policies that lower upfront capital costs. Following Australia's experience, a small-scale renewable portfolio standard is particularly worthy of consideration for further adoption.

Keywords:
business; policy; peer effect; solar photovoltaic panel; sustainability

JEL Classification:
M21; Q48; Q58; R38

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1. Introduction

Solar panels are a key green innovation given the importance of electricity as an input, the need to reduce emissions, and the fact that business processes are expected to continue to electrify over coming years (Helm and Hepburn, 2019). However the non-residential sector has generally lagged the residential sector in the adoption of distributed solar photovoltaic (PV) technology in Australia; as of June 2021 the cumulative capacity of small-scale solar PV installations by the residential sector was about four times that of the non-residential sector (AEMO, 2021). The substantial potential for growth in the use of solar PV by the non-residential sector motivates further analysis (Yoshino et al., 2019).

In this paper we make an early contribution on factors affecting non-residential uptake of solar PV panels, with a focus on distributed systems. While there have been numerous studies for the residential sector, including consideration of household-level factors such as household wealth (Best, 2022), our focus is the effect of policy interventions on non-residential solar adoption. We seek to answer a set of research questions that have not previously been specifically explored for either the non-residential or residential sector:

(i) How much of an effect has the national Small-scale Renewable Energy Scheme (SRES) had on the adoption of solar PV by Australia's non-residential sector?

(ii) Is there evidence of effects of solar PV adoption policies targeted at specific economic sectors such as agriculture?

(iii) Is non-residential solar PV uptake influenced by the sizes of businesses in an area?

(iv) Are there cross-sector solar PV adoption influences from the residential sector to the non-residential sector?

(v) Is there convergence in non-residential solar PV adoption across postcodes?

We pursue modelling approaches that utilize cross-sectional postcode-level data for Australia, the leading country in terms of per capita solar PV uptake, with over 600 watts of cumulative capacity per capita as of 2019 (IEA, 2020). Cross-sectional estimations are suitable given the rich cross-sectional variation available and constraints on panel data availability (Kwan, 2012; Crago and Chernyakhovskiy, 2017). In addition, we focus on the effects of variables that mostly vary geographically such as the SRES subsidy factor – a multiplier used to calculate the number of small-scale technology certificates (STCs) issued for new small-scale solar PV installations under the SRES. We control for various location effects such as Australia's climate zones. We also include a lagged dependent variable in some estimations to control for unobserved heterogeneity, allow a focus on factors influencing recent changes, and test for convergence effects over time. We also estimate a negative binomial model.

Our analysis differs to earlier studies in three key ways. First, we focus on the non-residential sector, whereas the prior literature has primarily focused on the residential sector (Reindl and Palm, 2021). This paper is the first on policy effects on non-residential solar PV adoption in Australia, a global frontier country when it comes to small-scale solar PV adoption. Second, our analysis considers sectoral and cross-sectoral influences, such as efforts to boost uptake of solar panels in the agricultural sector and possible impacts of residential uptake on non-residential uptake. Third, our inclusion of a lagged dependent variable in key specifications differs from the common approach in the literature and provides useful insights.

Understanding the factors that affect non-residential uptake of solar PV has the potential to inform broader narratives on private-sector corporate social responsibility (Kong et al, 2022) – an important research area given the links between energy, climate change, and financial outcomes (Bremer and Linnenluecke, 2017; Dodd and Nelson, 2019). For example, having solar panels may potentially boost the market valuations of businesses by lowering their exposure to emission reduction policies and costs and by promoting an environmentally friendly reputation (Choi et al. 2021).

The National Energy Law and the Australian National Energy Retail Rules (Australian Energy Market Commission, 2021) require energy retailers to classify distributed solar systems in Australia as either residential or “business” installations. The latter includes entities such as schools, government entities, and community organizations in addition to commercial businesses, so we refer to it as the “non-residential” sector. We use data on non-residential distributed installations from the Australian Energy Market Operator (AEMO, 2021). These installations do not include utility-scale solar farms built to export large volumes to the grid.

The organization of this paper is as follows. Section 2 discusses relevant prior research and a review of the economic and policy context. Section 3 discusses the methods and data. Section 4 presents the results. The final section is a concluding discussion.

2. Background

A discussion of existing research is provided in sub-section 2.1 and background on solar PV adoption in Australia’s non-residential sector in sub-section 2.2. The policy context is then discussed in sub-section 2.3.

2.1 Overview of previous literature

Research on small-scale solar panel uptake has predominantly focused on the residential sector. There have been recent contributions for many countries (for example Palm and Lantz, 2020; Gillingham and Bollinger, 2021; Horne et al., 2021; Hossain et al., 2021; Irwin, 2021; Reindl and Palm, 2021; Best, 2022). The predominant focus on the residential sector is in part likely to be because uptake by the non-residential sector has to date tended to be slower (Crago and Koegler, 2018). However solar PV is a technology that has recently become much more economically competitive.[1] Given the huge potential, solar PV adoption in the non-residential sector will likely be a growing focus of research and policy interest.

Peer influences and imitative adoption behavior have been extensively studied for the residential sector (Bollinger and Gillingham, 2012; Rode and Weber, 2016; Wolske et al., 2020; Balta-Ozkan et al., 2021). Studies have often found positive peer effects, with installations in an area encouraging further local uptake (Bollinger and Gillingham, 2012; Wolske et al, 2020). We are unaware of evidence of solar PV peer influences for the non-residential sector.

Perceptions, such as those relating to autonomy and independence, have also been identified as an important enabler of solar panel uptake in the residential sector. For instance, gaining greater independence from the energy retailer is known to have been a motivator for solar panel uptake in Australia and Denmark (Zander, 2020; Hansen et al., 2022). A sense of attachment to local communities has been described as being important for solar uptake decisions in California (Corbett et al., 2022). Political participation has also been correlated with solar panel uptake among US households (Mildenberger et al., 2019). There may be business-sector analogues for some of these influences.

There are some recent studies on the effects of various policies on solar PV uptake in the residential sector, including policies targeted at low-income households (O'Shaughnessy, 2022). Gillingham and Bollinger (2020) found a large impact of an economic and community-marketing policy intervention in the US. Palm and Lantz (2020) found that an information campaign had significant impacts on solar panel adoption by Swedish homeowners. De Groote and Verboven (2019) analyzed the effects of both upfront and ongoing policies in Belgium. There has also been residential-sector analysis of the effects of ongoing (Zander et al., 2021)

[1] Even a decade ago, solar panels were often viewed more as a promising than a mainstream technology (Ma et al., 2013). Costs have declined substantially and solar purchase decisions are now much more common.

and upfront subsidies (Best et al., 2021) in Australia. Our paper extends the application of policy-focused analysis to the non-residential sector.

Economic and physical factors have been found to be important for distributed solar PV uptake by the residential sector. For example, household wealth has been found to be important for uptake rates (Best et al., 2019a; Best et al., 2021; Best, 2022). Renting is also known to reduce the likelihood of residences having solar panels (Zander, 2020; Best, 2022), and living in apartments can also constrain household ability to install solar PV (Roberts et al, 2019). Similar effects may exist for the business sector – for example businesses without access to their own roof space face a major constraint to adopting solar PV. While data on access to roof space are not available, it is likely that small businesses are less likely to have their own roof space, all else equal. We use the number of employees as a general proxy for the size of businesses, although note that some businesses with large capitalizations might not have a particularly large number of employees.

The enablers of and barriers to residential solar panel uptake appear to have changed over time. Environmental concern was often an important enabler in the early years when panel costs were high (Palm, 2018; Palm, 2020). Interest in new technology can also be a motivator for some personality types (Palm, 2018; Palm, 2020; Hansen et al., 2022). On the other hand, aversion to new technology by some members of the public can inhibit adoption (Palm, 2018). Financial motivations may be increasingly important for late adopters given that they did not adopt for environmental or other reasons earlier on (Palm, 2020). Businesses may well also be relatively more likely to be motivated by financial considerations.

Nearly all prior studies on solar PV uptake by the non-residential sector have been forward-looking rather than based on observed historical data. Reindl and Palm (2021) assessed possible barriers and enablers in Sweden and summarized prior studies of a similar nature for other countries. Mah et al. (2018) reported interview-based perceptions among potential solar PV adopters in Hong Kong, including commercial operators. They found that policy preferences differed between residential and non-residential sectors, with residential interviewees often preferring upfront subsidies and commercial interviewees often preferring feed-in tariffs.

There have been a small number of studies of non-residential solar PV uptake in the US. Crago and Koegler (2018) found that multiple types of policies have been important for commercial-scale solar PV capacity in the north-east, while Frey and Mojtahedi (2018) focused on the positive impact of the California Solar Initiative. Given the scale of the solar PV opportunities for businesses around the world, more attention to key factors in a solar early-mover such as Australia may be useful.

2.2 Non-residential sector solar uptake in Australia

This paper focuses on factors affecting uptake of solar PV panels by the non-residential sector in Australia's National Electricity Market (NEM), a region that includes much of the country's population outside of Western Australia and the Northern Territory. Postcode-level information on distributed energy installations and capacity by customer type from the Distributed Energy Resources Register AEMO (2021) are used. As noted, the data exclude utility-scale operations producing electricity primarily for the grid.

The average size of non-residential solar PV systems for the non-residential sector was about 18 kilowatts as of June 2021. For the residential sector, this was about 4 kilowatts. An example of a larger non-residential installation is the 280 kilowatt McLean Farms installation in Queensland (AEMO, 2021; Todae Solar, 2021). The output from this solar system is predominantly used to help power an egg farm.

Figure 1 shows that the ratio of non-residential solar installations to residential installations among NEM states tends to be about 0.1, with substantial geographical variation. The highest ratio is for Victoria – a state with relatively high non-residential uptake and relatively low residential uptake (AEMO, 2021).

Figure 1. The ratio of distributed non-residential to residential-sector solar installations in each jurisdiction of the National Electricity Market for June 2021.

Note: The Australian Capital Territory (ACT) is not shown as it is an outlier, with a value of 0.45. Data: AEMO (2021).

2.3 Policy context

The key small-scale solar adoption policy at the national level has been the Small-scale Renewable Energy Scheme (SRES), part of Australia's Renewable Energy Target (RET). In place since 2011, the SRES is a renewable portfolio standard (RPS) that provides varying support per kilowatt of solar PV capacity based on solar exposure, with Australia divided into four zones to achieve this. This scheme is not a traditional subsidy paid by the government. Instead, the installation of small solar systems leads to the generation of small-scale renewable energy certificates (known as STCs), and these can be used by electricity retailers and others to meet compliance requirements under the SRES. The SRES applies for installations of up to 100 kilowatts (AEMO, 2021), which covers the majority of the non-residential installations in our dataset. Larger systems fall under the Large-scale Renewable Energy Target (LRET).

The SRES subsidy for a new small-scale solar PV system is a product of four terms: a subsidy factor; the system's power generation capacity; a deeming period that has reduced by one year annually since 2016; and a certificate price that has typically remained close to the fixed available clearing house price of A$40. The subsidy factor is the only aspect of SRES scheme design that has varied cross-sectionally, with a higher factor applied for locations better suited to solar PV production. There are four zones, with subsidy factors of 1.185, 1.382, 1.536, and 1.622, respectively. Minor changes to the SRES saw some postcodes reallocated between zones on 1 January 2020 (Australian Government, 2019). This affected about 9% of postcodes in this study.

Solar promotion policies have also been introduced by Australia's states and territories, including some early premium feed-in tariff schemes and a range of policies targeting the upfront cost of solar panels. The Australian Government (2021) lists nine initiatives that aimed at reducing upfront costs and commenced prior to 2020. These include the NSW *Farm Innovation Fund* that provides loans for on-farm infrastructure, an ACT battery discount scheme that applies to solar-battery installations, and seven schemes in Victoria, Australia's second-most populous state, which are:

- An *Agriculture Energy Investment Plan* (AEIP), which aims to help Victorian farms reduce energy costs via grants (Victorian Government, 2021a). Over 450 grants totalling A$22 million had been awarded by March 2021 (Victorian Government, 2021b). An example is a grant to a vineyard in central-west Victoria that had an energy assessment carried out in June 2019 and subsequently installed a 21-kilowatt solar PV system under the AEIP (Victorian Government, 2020). The AEIP was initially in place from late 2018 to mid-2020 and then extended in the 2020–2021 state budget.

- An *Environmental Upgrade Finance* scheme for commercial buildings. For example, a 15-kilowatt system on the Rubato Building in Brunswick, Melbourne benefitted from this scheme in 2019 (Moreland City Council, 2019).

- Five variants of the *Sustainable Finance for Energy Solutions* scheme run by Sustainability Victoria. These use financial instruments with various specifications regarding collateral, repayments, and purchase options.

3. Methods and data

Our approach to modelling non-residential solar panel installations at the postcode (p) level in the NEM is:

$$B_p = \alpha + \boldsymbol{P'_p\psi} + \boldsymbol{D'_p\delta} + \boldsymbol{L'_p\lambda} + \rho R_{p,t-1} + \mu B_{p,t-1} + \varepsilon_p \qquad (1)$$

We use several dependent variables for non-residential solar PV installations (B) in each postcode. The first is the log of the cumulative count of solar installations in the postcode. Others include the number of new installations during the year (unlogged) and the log of the cumulative non-residential solar capacity. The dependent variables are measured as of June 2021 (AEMO, 2021) and only include non-residential distributed solar PV systems. Solar thermal installations (typically for hot water supply) are not considered. The model has α as the constant term and ε as the error. We use both ordinary least squares and negative binomial estimations.

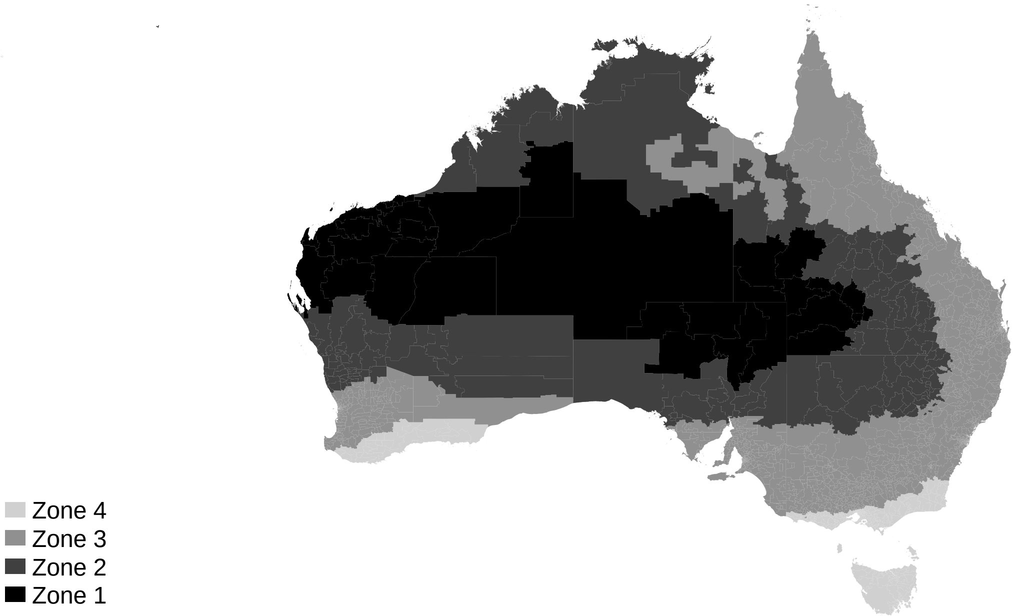
$\boldsymbol{P}$ represents a policy vector that includes the log of the SRES subsidy factor. Higher factors accord with sunnier conditions and stronger policy support per kilowatt of capacity installed. Figure 2 shows the 2020 values of these subsidy factors.[2] Conditioning on climate zone variables (discussed further below), we seek to identify the effect of the log SRES subsidy factor. An alternative that we also pursue is to control for the log solar exposure instead of climate zones, although this leads to high multicollinearity. $\boldsymbol{P}$ also includes an interaction between a binary variable for the state of Victoria and the agricultural proportion of businesses in a postcode to test whether Victoria's agriculture-focused policy interventions have had a detectable effect on adoption.

The $\boldsymbol{D}$ vector includes business and building characteristics. The coefficient vector is $\boldsymbol{\delta}$ in this case.[3] The log of the number of businesses is included to control for a scale effect, as postcodes with more businesses would likely have more non-residential solar installations, all else equal. $\boldsymbol{D}$ also includes variables measuring the proportions of businesses in several size ranges based on the number of employees. Small businesses operating within a shopping centre or an office building often face physical constraints such as not having their own roof, making it difficult or impossible to install solar PV. Medium and larger businesses are more likely to have their own roof space. The proportion of residential dwellings that are apartments is also used as a proxy for building density in the postcode.

[2] The analysis in Section 4 uses the pre-2020 zones to explain the level of non-residential installations because the majority of installations were prior to 2020. Specifications that control for the lagged dependent variable effectively evaluate factors affecting the change in non-residential installations for the year to June 2021. For these, the post-2020 zones are used.

[3] Coefficients are also shown for each other vector or variable.

Figure 2. SRES zones operating since 1 January 2020.



Note: The SRES factors are 1.185, 1.382, 1.536, and 1.622 for zone 4, 3, 2, and 1 respectively. Data: Australian Government (2019).

D also includes a variable for the proportion of businesses in the postcode that are agricultural.[4] This is because farms tend to be relatively well suited for solar panels due to having available space on land, roofs, and water bodies. Some farms also have high electricity use and thus a strong incentive to adopt solar panel systems so as to lower electricity bills, for example horticultural and poultry operations (Victorian Government, 2021a).[5] A survey of business customers by an electricity distributor in New South Wales (NSW) identified the agricultural sector as having the highest share of solar customers among all business sectors (Ausgrid, 2018).

Our business variables are constructed using ABS (2021) data. The data are for entities with an Australian Business Number (ABN) that are actively trading and remitting goods and services tax (GST) to the Australian Taxation Office (ABS, 2021). This definition captures the key businesses in Australia. It omits sole traders that do not register for GST.

The available business data provide the principal address of each business. One consideration is that large businesses often have operations in numerous postcodes; the principal address (headquarters) of most large businesses tends to be in a central business district such as the

[4] Controlling for only one sectoral share reduces multicollinearity issues. Including 18 sectoral shares can increase the average variance inflation factor in the first regression of Section 4 to 424.
[5] Dairy farms also use a lot of electricity, although much is in the early mornings when solar conditions are not yet optimal.

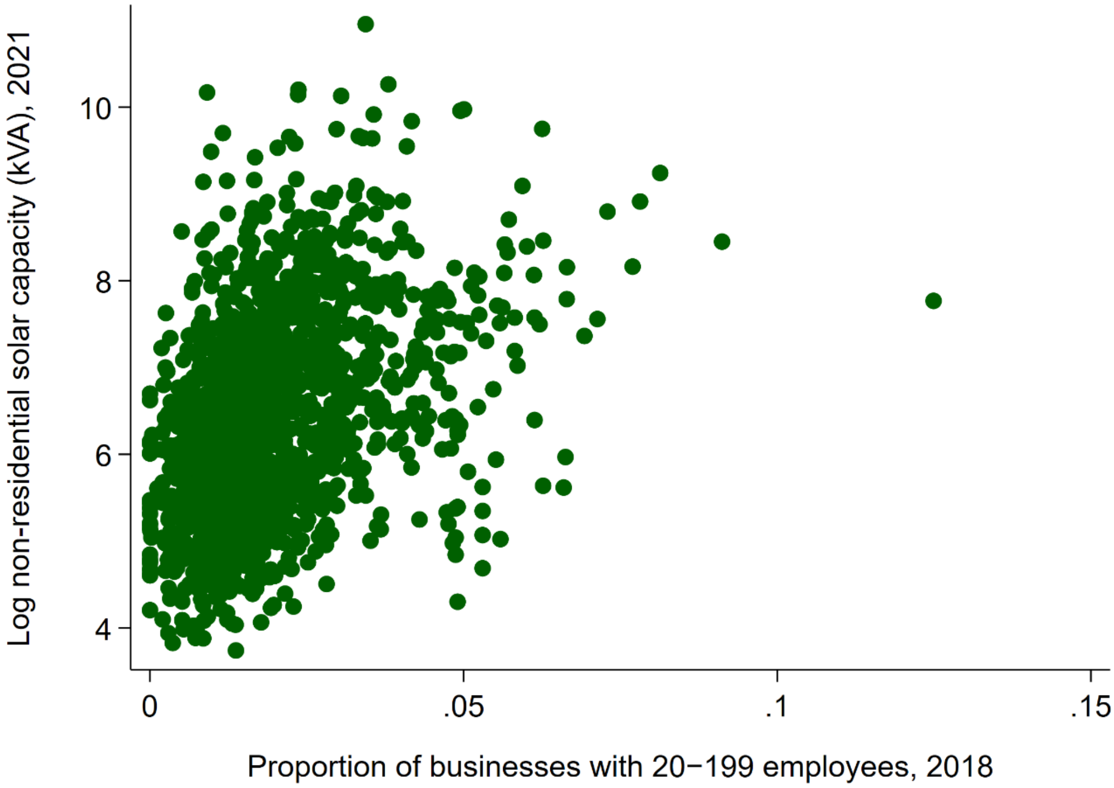
centre of Sydney or Melbourne. It is not possible to apportion business operations across postcodes based on the data we have. Given that central business districts tend to be highly dense, it might be expected that postcodes with many large businesses (based on overall employee counts) do not have a commensurately higher number of non-residential solar installations. An additional issue is that some businesses are registered to a residential address and able to benefit from a residential solar system (Small Business Commissioner, 2022), although the omission of businesses that do not register for GST reduces this issue.

Figure 3 is suggestive of a positive relationship between the proportion of businesses with 20–199 employees (mid-sized businesses) in a postcode and the log of non-residential solar capacity. This is an initial indication that having more mid-sized businesses tends to be associated with additional solar PV adoption by the non-residential sector. A positive relationship also exists if using the log of the count of businesses with 20–199 employees, although this also captures a scale effect. Relative to small businesses, medium-sized businesses are likely to have larger energy needs and greater access to resources for investment in solar panels.

Equation (1) also includes location-specific binary variables ($\boldsymbol{L}$) to control for policy and other differences across states and territories. Binary variables for four states and the ACT are included, with the reference state being Queensland. Binary variables are also included for a climate zone designation used by the Australian Energy Regulator (2019). Postcodes are assigned to one of six underlying climate zones, and then split into regional or city classifications in most cases. A total of 11 climate and city zone binary variables are included. The possibility of multicollinearity between these and the state variables will be considered by viewing variance inflation factors. The climate zones cut across state borders.

Industry momentum effects are interesting to consider. Having more non-residential solar PV installations could slow the subsequent growth rate in non-residential sector uptake of solar panels as the industry matures and the rate of expansion moderates. The subsequent rate of non-residential uptake of solar PV in a postcode could alternatively rise due to a positive demonstration effect, or due to having greater access to solar installers. Such effects will be tested by including a lagged cumulative installations variable. This is measured as of June 2020 ($t - 1$), the first date for which solar PV data are available from AEMO (2021).

Figure 3. The proportion of businesses with 20–199 employees and the log of non-residential- distributed solar PV capacity (June 2021).



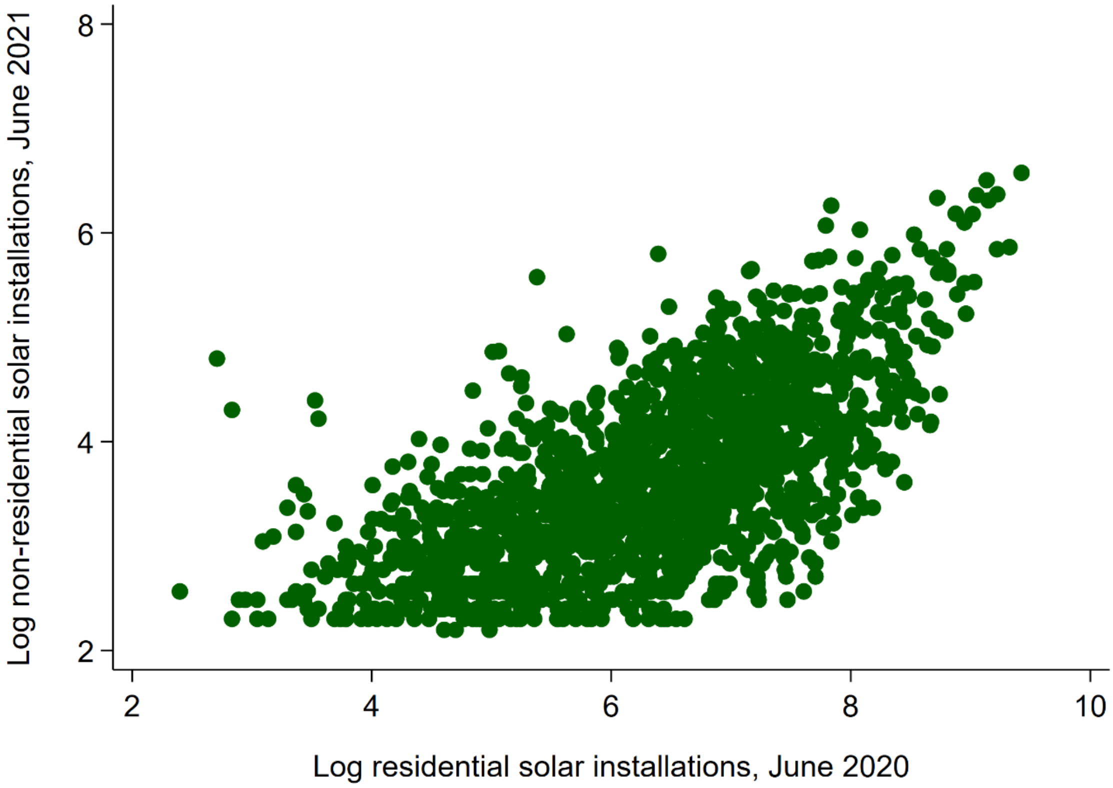
Note: Each postcode is shown by a dot. Data: AEMO (2021); ABS (2021).

When controlling for cumulative non-residential installations (logged) up to the prior year, estimated effects are on the annual change rather than the level of the dependent variables. This allows for the assessment of either convergence or divergence in solar PV adoption paths across postcodes over time. Lagged dependent variable approaches have also been applied in earlier contexts (e.g. Best and Burke, 2019).

It is also possible that having more residential installations in a local area encourages non-residential installations. This motivates the use of the explanatory variable *R*, the log number of cumulative residential solar installations as of June 2020. This variable is also likely to help control for key aspects of unobserved heterogeneity that underpin both non-residential and residential installation rates. A positive relationship is evident in Figure 4.

Correspondence tables (ABS, 2020) are used to match data for business size and type from the Statistical Area Level 2 (SA2) to the postcode-level solar adoption data. SA2 and postcode areas are roughly similar in size, although were developed for different purposes (the Australian Statistical Geography Standard and postal services, respectively). The conversion process introduces a degree of measurement error, however this is unlikely to be systematically correlated with the explanatory variables.

Figure 4. Log of cumulative non-residential distributed solar PV installations as of June 2021 versus the log of cumulative residential-sector distributed solar PV installations as of June 2020.



Note: Each postcode is shown by a dot. Data: AEMO (2021).

Table 1 provides the variable definitions and summarizes the data sources. Descriptive statistics are shown in Table 2. There was an average of 58 cumulative non-residential distributed solar PV installations per postcode as of June 2021, seven of which were new installations over the prior year. Due to privacy restrictions, data on non-residential solar PV installation data are not available for postcodes that have fewer than 10 distributed installations (AEMO, 2021).

Table 1. Variable descriptions

Variable	Vector	Description
Solar panels, 2021 (NR)	B	Count of non-residential (NR) solar PV panel installations as of June 2021 (cumulative).
Solar additions 2020-21 (NR)	B	Count of non-residential solar PV installations for the year to June 2021.
Solar capacity, 2021 (NR)	B	Capacity in kilovolt-ampere of non-residential solar PV installations (cumulative) as of June 2021. Kilovolt ampere (kVA) is a measure of apparent power, whereas kilowatt (kW) is a measure of real power. These two measures are equivalent if the power factor is one but will differ otherwise. Our key results are in the form of elasticities and semi-elasticities, so are independent of the underlying units of the dependent variable.
SRES factor	P	Small-scale Renewable Energy Scheme factor: 1.622 (zone 1), 1.536 (zone 2), 1.382 (zone 3), 1.185 (zone 4).
Count of businesses	D	Number of businesses (total). Multi-location businesses are attributed based on the main business address. Only businesses with an ABN and that are actively trading and remitting GST are counted.
Agricultural businesses	D	% of businesses in agriculture, forestry and fishing / 100
Reference: 0 employees		% of businesses employing no-one / 100
Business %/100, 1–4 employees	D	% of businesses with 1–4 employees / 100
Business %/100, 5–19	D	% of businesses with 5–19 employees / 100
Business %/100, 20–199	D	% of businesses with 20–199 employees / 100
Business %/100, 200+	D	% of businesses with 200+ employees / 100
Apartments per dwelling	D	The number of units divided by the number of dwellings.
Reference: Queensland		Binary variable equal to 1 for postcodes in Queensland.
Australian Capital Territory	L	Binary variable equal to one for postcodes in the ACT.
New South Wales (NSW)	L	Binary variable equal to one for postcodes in NSW.
South Australia	L	Binary variable equal to 1 for postcodes in South Australia.
Tasmania	L	Binary variable equal to one for postcodes in Tasmania.
Victoria	L	Binary variable equal to one for postcodes in Victoria.
Climate and city zones	L	11 zones designated by the Australian Energy Regulator. These are 1. Climate zone (CZ) 1 and regional; 2. CZ2 and city/suburban; 3. CZ2 and regional; 4. CZ3&4 and regional; 5. CZ5 and city and NSW; 6. CZ5 and city and SA; 7. CZ5 and regional; 8. CZ6 and city; 9. CZ6 and regional; 10. CZ7 and city; 11. CZ7 and regional.
Solar panels, 2020 (res)	R	Count of residential solar PV installations as of June 2020 (cumulative).
Solar panels, 2020 (NR)	B	Count of non-residential solar PV installations as of June 2020 (cumulative).
Solar capacity, 2020 (res)	R	Capacity (kVA) of residential solar PV installations as of June 2020 (cumulative).
Solar capacity, 2020 (NR)	B	Capacity (kVA) of non-residential solar PV installations as of June 2020 (cumulative).
Victoria * Ag (%/100)	P	An interaction variable: binary variable for Victoria * agriculture % /100
Financial % of businesses	D	% of businesses in Financial and Insurance Services / 100

Notes: Solar data are from AEMO (2021). Business size and type are based on 2018 data (ABS, 2021). The SRES factors are from Australian Government regulations (2019). Apartments and dwellings are from the 2016 census data (ABS, 2018). “Vector” refers to the categories in equation (1).

Table 2. Descriptive statistics

	Minimum	Mean	Maximum
Solar panels, 2021 (NR)	9	58.04	717
Solar additions during the year to June 2021 (NR)	0	6.76	125
Solar capacity, 2021 (NR)	42.1	1366.48	57344.58
Solar (NR) / solar (res), 2021	0.01	0.11	8.07
SRES factor	1.185	1.33	1.622
Count of businesses	13	1200.94	42127
Agricultural %/100 of businesses	0	0.21	0.71
Share (%/100) of businesses with:			
0 employees	0.38	0.63	0.83
1–4 employees	0.15	0.26	0.41
5–19 employees	0	0.09	0.23
20–199 employees	0	0.02	0.12
200+ employees	0	0.00	0.01
Apartments divided by dwellings	0	0.09	0.93
State or territory			
Queensland	0	0.22	1
Australian Capital Territory	0	0.01	1
New South Wales	0	0.27	1
South Australia	0	0.16	1
Tasmania	0	0.03	1
Victoria	0	0.30	1
Solar panels, 2020 (res)	11	1059.41	12402
Solar panels, 2020 (NR)	5	51.37	620
Solar capacity, 2020 (res)	41	4356.57	50595.02
Solar capacity, 2020 (NR)	29.6	1130.05	56333.96
Victoria * Ag (%/100)	0	0.07	0.71
Financial %/100 of businesses	0.01	0.06	0.40

Notes: SRES stands for Small-scale Renewable Energy Scheme. There are 1,595 observations. The mean for the agricultural share of businesses is relatively high because there are some small postcodes (by population) with high percentages of businesses in agriculture. The data are mostly from June, while census data (apartments per dwelling) are from August. The mean for the SRES factor of 1.33 is for pre-2020 zones. For post-2020 zones, it changes to 1.34.

4. Results

4.1 Main results

Table 3 shows ordinary least squares (OLS) results for the log of the cumulative count of non-residential solar systems as of June 2021. Column (1) excludes the climate and city zone locational variables. The variance inflation factor averages 2.18, suggesting that multicollinearity is not a major issue. When climate and city zone locational variables are included, this rises to 4.49, still well below the common threshold of 10. Further, the sign and significance of most variables is similar in column (2) and some magnitudes are also similar. We thus retain the climate and city zone variables for the subsequent estimations. Moderate multicollinearity has the somewhat benign implication of raising standard errors.

Table 3. Results: OLS regression for the log non-residential solar PV installation count as of June 2021

	(1)	(2)	(3)	(4)
Log SRES factor	1.948***	1.502***	1.474***	0.141*
	(0.324)	(0.336)	(0.334)	(0.080)
Log count of businesses	0.656***	0.679***	0.340***	0.019***
	(0.020)	(0.021)	(0.040)	(0.007)
Agricultural %/100 of businesses	0.914***	0.245**	1.031***	-0.023
	(0.098)	(0.122)	(0.129)	(0.027)
Share (%/100) of businesses with:				
1–4 employees	-1.095***	-0.752*	-1.146***	-0.172*
	(0.404)	(0.437)	(0.414)	(0.093)
5–19 employees	7.335***	5.627***	6.444***	0.248*
	(0.609)	(0.579)	(0.596)	(0.138)
20–199 employees	8.241***	9.807***	13.354***	0.839***
	(1.702)	(1.637)	(1.555)	(0.315)
200+ employees	-18.190	-8.944	-6.195	-1.972
	(14.704)	(14.140)	(12.183)	(2.901)
Apartments per dwelling	-1.505***	-1.362***	-0.069	-0.064**
	(0.102)	(0.109)	(0.156)	(0.030)
State or territory. Reference: Queensland				
Australian Capital Territory	-0.688***	-0.390**	-0.632***	-0.058
	(0.091)	(0.166)	(0.176)	(0.047)
New South Wales	-0.561***	-0.481***	-0.514***	-0.108***
	(0.039)	(0.050)	(0.047)	(0.009)
South Australia	0.190***	0.367***	0.091	-0.034**
	(0.042)	(0.060)	(0.063)	(0.013)
Tasmania	-0.297***	-0.389***	-0.486***	-0.001
	(0.077)	(0.096)	(0.092)	(0.025)
Victoria	0.106*	0.219***	0.170***	0.038**
	(0.056)	(0.063)	(0.062)	(0.017)
Log solar panels, 2020 (res)			0.387***	0.005
			(0.037)	(0.006)
Log solar panels, 2020 (NR)				0.970***
				(0.007)
Victoria * Ag (%/100)				0.083**
				(0.035)
Climate and city zones	No	Yes	Yes	Yes
Adjusted R^2	0.648	0.677	0.715	0.987
Mean variance inflation factor	2.18	4.49	5.16	5.56

Notes: ***, **, * show statistical significance at 1, 5 and 10 per cent levels respectively. Robust standard errors are in brackets below the coefficients. SRES stands for Small-scale Renewable Energy Scheme. There are 1,595 observations for each column. SRES zones are pre-2020 for columns (1)–(3) because most installations were from pre-2020. SRES zones are post-2020 for column (4), because this column effectively assesses the change in non-residential installations due to the introduction of the lagged dependent variable. Use of the post-2020 zones for columns (1)–(3) gives SRES coefficients that are similar but slightly smaller, as expected. The reference business size is 0 employees.

Positive and significant coefficients for the log SRES factor are obtained in each column of Table 3. Columns (2)–(3) show positive coefficients of 1.5, significant at the 1% level, even with the climate and other controls included. These coefficients are elasticities given that both the dependent and independent variables are logged, and indicate that a 1% increase in the subsidy factor is on average associated with a 1.5% increase in the count of non-residential solar systems, all else equal. Column (4) effectively gives an impact on the change in solar installations rather than the level.

As expected, the coefficients for the log of the number of businesses in each postcode are positive in Table 3, indicative of a scale effect. It is reasonable that the elasticity is less than one given that the average physical size of a business is likely to be smaller in postcodes with more businesses.

A positive coefficient is found for the agricultural share of businesses in column (2) of Table 3, with the coefficient indicating that a percentage point increase in the agricultural share is on average associated with 0.28 percent more non-residential installations of solar panels.[6] This is in line with expectations that farms and related businesses are particularly suited to solar PV given their space endowments and, in some instances, their energy needs.

Table 3 also provides evidence for effects of the size of businesses, with positive and significant coefficients obtained for the proportions of businesses with 5–19 or 20–199 employees. The reference case is the proportion of businesses without any employees. It is of interest that the coefficient for large businesses (200+ employees) is insignificant. This likely relates to the earlier discussion that these businesses tend to be headquartered in central business districts where there is high building density.

Table 3 also shows some significant coefficients for the state variables. There are positive and significant coefficients for Victoria, the state with the most extensive solar interventions for the business sector, despite receiving less sunshine than the base case of Queensland. Interestingly, the opposite was observed for the residential sector (Best et al., 2019a).

While not a non-residential variable, the proportion of residences that are apartments is included as a useful proxy of overall density. As expected, there are negative coefficients for this variable in Table 3. The variance inflation factor reaches around 10 if the log of solar exposure is included (estimates not reported). The signs and significance of key regression coefficients, including the log SRES subsidy factor, are similar either way.

Column (3) of Table 3 includes the one-year lag of the log of the cumulative count of residential solar panel installations in each postcode. There is a positive and significant coefficient for this variable. This may be picking up other influences in each postcode that are relevant for solar

[6] Calculated based on the exponential of 0.245 minus one.

panel adoption. It may also be at least in part picking up a cross-sectoral effect such that having more residential panels has a positive influence on subsequent installations by the non-residential sector.

Column (4) of Table 3 introduces the lagged log of the number of non-residential solar installations, making this a cross-sectional lagged dependent variable model. There is an elasticity of 0.97 for this variable. As this is significantly different from one at the 1% level, the coefficient reveals convergence over time across postcodes.[7] This means that the growth rate in non-residential solar uptake is lower in postcodes with higher initial levels.

The inclusion of the lagged variable in column (4) of Table 3 implies that the coefficients for other variables now represent the impact on the annual growth rate in non-residential solar installations from 2020 to 2021. It is likely that many coefficients would remain similar in sign given that many solar systems have been installed only recently. This is indeed the case, with the exception of the coefficient for South Australia – the overall findings indicate that South Australia has a high number of non-residential solar PV systems, but that uptake over the 12 months to June 2021 was relatively slow, all else equal. The SRES coefficient being less significant is reasonable given that the base level of installations was already likely higher in areas with a higher subsidy factor.

Column (4) of Table 3 also includes an interaction between the Victoria binary variable and the agricultural share of businesses in each postcode. A positive and significant coefficient is found. This may reflect effects of the state's solar PV promotion efforts targeting the sector, including the AEIP (Victorian Government, 2021a).

The estimates in Table 3 remain qualitatively similar when changing the proportional explanatory variables to log transformations of the counts and dropping the control for the log number of businesses. This induces greater multicollinearity, however. Key results are also qualitatively similar for a dependent variable equal to the ratio of non-residential installations to the number of businesses. This specification does not require the log count of business numbers as a control, as the dependent variable has the number of businesses in the denominator.

[7] To see this, one can subtract the lagged log non-residential uptake from both sides of the model. The left-hand side would then be the proportional growth rate. The coefficient for the lagged dependent variable would then equal 0.97 – 1 = –0.03. Thus postcodes with more non-residential solar PV installations in 2020 had a slower proportional growth rate in the number of installations over the subsequent year.

Further robustness tests (unreported) also support the result for the SRES subsidy factor. For example, state sub-samples produce some positive SRES coefficients, although reduced statistical significance of effects is obtained for these relatively small subsamples. A binary variable for SRES zone 4 (the zone with the lowest subsidy factor) is also negative and significant when used in place of the log SRES factor, as expected. In addition, log SRES coefficients are still positive and significant when further locational controls are added, for example 41 binary controls based on the first two digits of a postcode. This approach can control for geographical clusters to a reasonable extent.

4.2 Negative binomial model results

Table 4 displays the results of a negative binomial estimation, with the dependent variable here being the number of new installations of non-residential solar panels over the year to June 2021. A negative binomial model is suitable given the use of an integer dependent variable and the skewed distribution of non-residential solar installations across postcodes. The results are generally consistent with column (4) of Table 3, although statistical significance varies in some cases. The SRES variable remains positive and significant at the 1% level. A robust relationship is evident for the influence of the proportion of mid-sized businesses (20–199 employees).

A difference in Table 4 is that the coefficient for the agricultural share of businesses becomes negative and significant for outside Victoria, in contrast to the insignificant coefficient in column (4) of Table 3. This suggests that, outside Victoria, solar panel uptake during the year to June 2021 was on average lower in areas with a higher share of agricultural businesses, all else equal. The interaction between the Victoria binary variable and the agricultural share of businesses remains positive and significant at the 1% level, with the coefficient suggestive of strong growth in installations in rural areas of Victoria in the year to June 2021.

Table 4. Results: Negative binomial regression for additions to non-residential solar PV panels in the year to June 2021 (unlogged)

	Coefficient	Standard error
Log SRES factor	1.764***	(0.477)
Log count of businesses	0.159***	(0.055)
Agri. %/100 of businesses	-0.732***	(0.270)
Share (%/100) of businesses with:		
1–4 employees	-0.331	(0.743)
5–19 employees	0.287	(1.114)
20–199 employees	8.036***	(2.359)
200+ employees	-15.402	(15.939)
Apartments per dwelling	-0.586***	(0.227)
State or territory. Reference: Queensland		
Australian Capital Territory	-0.901***	(0.261)
New South Wales	-2.025***	(0.140)
South Australia	-0.659***	(0.139)
Tasmania	-0.142	(0.206)
Victoria	-0.216	(0.159)
Log solar panels, 2020 (res)	0.006	(0.052)
Log solar panels, 2020 (NR)	0.803***	(0.045)
Victoria * Ag (%/100)	1.395***	(0.279)

Notes: ***, **, * show statistical significance at 1, 5 and 10 per cent levels respectively. Robust standard errors are in brackets beside the coefficients. SRES stands for Small-scale Renewable Energy Scheme. There are 1,595 observations. The pseudo R-squared is 0.192. The number of non-residential installations is reported as lower in June 2021 compared to June 2020 for 89 postcodes (out of 1,595). A value of zero is used for the solar additions in these cases to allow for a non-negative dependent variable. 71 of the 89 postcodes report solar panels being lower by 1 in 2021. Climate and city zone controls are included. SRES zones are post-2020.

4.3 Solar capacity results

Table 5 investigates impacts on log non-residential solar capacity (rather than installation counts). Many of the estimated effects remain similar in sign and significance. The SRES coefficient is again positive and significant, with an elasticity of around 1.2–1.3 in columns (1)–(2). There is also a positive and significant influence in column (3) on the proportional change in installations over the year to June 2021. Scale effects are evident in the positive coefficient for the log number of businesses. The coefficient of 0.48 for Victoria in column (1) implies that non-residential solar capacity is 62% (100 * {exp(0.48) –1}) higher there than in Queensland, after accounting for the effects of the control variables.

Table 5. Results: OLS regression for log cumulative capacity of non-residential solar PV as of June 2021

	(1)	(2)	(3)
Log SRES factor	1.329**	1.209**	0.312*
	(0.520)	(0.522)	(0.165)
Log count of businesses	0.771***	0.387***	0.042*
	(0.031)	(0.056)	(0.021)
Agricultural %/100	-0.093	0.739***	
	(0.179)	(0.193)	
Share (%/100) of businesses with:			
1–4 employees	-1.400**	-1.964***	-0.127
	(0.650)	(0.645)	(0.248)
5–19 employees	6.249***	7.318***	0.188
	(1.072)	(1.086)	(0.477)
20–199 employees	19.996***	23.902***	2.375***
	(2.460)	(2.419)	(0.792)
200+ employees	-9.230	-4.902	-4.781
	(21.388)	(19.654)	(5.087)
Apartments per dwelling	-1.333***	0.193	-0.078
	(0.189)	(0.247)	(0.066)
Reference: Queensland			
Australian Capital Territory	0.251	-0.018	-0.098
	(0.260)	(0.249)	(0.079)
New South Wales	-0.542***	-0.566***	-0.266***
	(0.078)	(0.076)	(0.040)
South Australia	0.525***	0.212**	-0.169***
	(0.104)	(0.107)	(0.050)
Tasmania	-0.069	-0.133	-0.048
	(0.178)	(0.176)	(0.101)
Victoria	0.483***	0.491***	-0.034
	(0.098)	(0.097)	(0.045)
Log solar capacity, 2020 (res)		0.435***	0.030**
		(0.050)	(0.013)
Log solar capacity, 2020 (NR)			0.918***
			(0.018)
Financial %/100 of businesses			-0.518***
			(0.189)
Climate and city zones	Yes	Yes	Yes
R^2	0.578	0.603	0.949

Notes: ***, **, * show statistical significance at 1, 5 and 10 per cent levels respectively. Robust standard errors are in brackets below the coefficients. SRES stands for Small-scale Renewable Energy Scheme. There are 1,595 observations for each column. SRES zones are pre-2020 for columns (1)–(2) because most installations were from pre-2020. SRES zones are post-2020 for column (3), because this column effectively assesses the change in non-residential solar capacity due to the introduction of the lagged dependent variable.

Column (3) of Table 5 investigates the impact of the share of businesses in the financial sector. A strong negative association is found. This makes sense given that financial companies are often located in densely-populated areas that tend to have fewer opportunities for solar installations relative to other areas. Other regressions in the available Stata code show a positive and significant coefficient for the manufacturing share of businesses and an insignificant coefficient for the retail share.

A difference in Table 5 is the positive and significant coefficient for the log cumulative residential-sector solar system capacity from the prior year, even when controlling for a similar non-residential variable in column (3). Specifically, 1% more in the way of residential solar system capacity is found to be associated with 0.03% more non-residential solar PV capacity being added in the following year, all else equal. This may be suggestive of cross-sector peer influences such that higher residential solar capacity promotes additional non-residential capacity. It may also be due to other factors such as the beneficial effects of having a larger local installation sector.

Evidence of convergence is again observed in column 3 of Table 5, where it can be seen that postcodes with substantial non-residential sector solar PV capacity tend to subsequently have lower capacity growth rates. Such convergence effects make intuitive sense given that this is a technology that is broadly suitable across the whole of Australia and for which there are catch-up investment opportunities in locations that fall behind.

5. Discussion and conclusion

5.1 Discussion of the main results and context

The estimation results provide evidence that a national-level policy – the SRES – appears to have had an important effect in promoting distributed solar PV adoption by the non-residential sector in Australia. Targeted initiatives also appear to have been important, as evidenced by greater non-residential sector deployment of solar panels in agricultural areas in Victoria, a state with various initiatives to promote business-sector adoption of solar PV. Further, we found that postcodes with higher shares of businesses that are medium-sized have more non-residential solar panel adoption, all else equal. A positive influence of residential-sector capacity on non-residential capacity may be indicative of cross-sectoral peer effects. A supply-side explanation is also possible, as local availability of installers is likely to induce additional decisions to install. The variable may also possibly be picking up the effect of other local factors.

The effects of the SRES for the non-residential sector are similar to what has been earlier estimated for all small-scale systems in Australia. Specifically, the SRES subsidy factor elasticity of solar capacity is here found to be around 1.2–1.3 for the non-residential sector (Table 5), having earlier been estimated to be in the range 0.6–1.6 for all systems (Best et al, 2019b). An important difference to the residential sector is that the results suggest relatively high uptake of distributed solar PV by the non-residential sector in Victoria, including in agricultural areas. This may reflect the concerted policy efforts for the agricultural sector in particular in this state via initiatives including the AEIP.

While the existing literature has focused mainly on distributed solar PV uptake in the residential sector (Reindl and Palm, 2021), our analysis is for non-residential installations. Our results are most directly comparable to the studies of Crago and Koegler (2018) and Frey and Mojtahedi (2018) for the US, which also found an important general influence of business-sector policies. Frey and Mojtahedi (2018) found that a 10% increase in the per-kilowatt subsidy on average leads to about 2% more solar capacity in the non-residential sector in California. Our study shows a larger impact of around 12% in Australia. Our analysis also contributes in terms of its findings of business-size impacts and possible cross-sector influences.

The results also identify links between past solar uptake levels and subsequent growth rates. Specifically, greater non-residential solar uptake in a postcode is associated with a lower subsequent growth rate in uptake. This implies convergence over time such that areas with low initial uptake tend to catch up rather than fall even further behind. For regions that are yet to have much in the way of non-residential solar PV installations, the implication is that short-term support can be important to help get the industry started. Once an initial level of adoption has been seen, the growth rate of solar adoption is likely to be higher in such areas than in areas with more mature adoption levels.

5.2 Relating the results to the research questions

With regards to the first two research questions, we find that both national policy and targeted initiatives appear to have been important drivers of non-residential solar panel uptake in Australia. Our research provides the specific case studies of the SRES and agricultural sector policies, with the findings being consistent with the prior that subsidies are a key enabler for solar-panel uptake (Reindl and Palm, 2021). A key finding with respect to the third research question is a positive link between mid-sized businesses and solar-panel uptake. With regard to the fourth research question, some evidence of cross-sectoral peer influences from the residential to the non-residential sector has been found. This complements evidence of peer effects within the residential sector (Bollinger and Gillingham, 2012). With respect to the fifth question, evidence of geographical convergence in non-residential solar PV uptake has also been found.

Overall, the results provide evidence that state and federal governments in Australia have had important influences on non-residential solar PV adoption outcomes via policy schemes. Over time, these could be recalibrated to focus on emerging market shortcomings or policy goals. For example, policy could be focused on battery adoption or the encouragement of greater adoption of solar PV in remote regions where installation costs tend to be higher but where public benefits in the form of reducing the need to invest in transmission and distribution grid infrastructure may be larger. Other countries may also be able to learn from Australia's early experience, especially when it comes to the use of a renewable portfolio standard approach focused on small-scale installations in the form of the SRES. The estimates will also be able to inform understanding of likely future uptake patterns in Australia and elsewhere.

5.3 Limitations and future research

Limitations of the analysis include that we do not have access to solar PV installation data by type of non-residential premises (e.g. business; school; other). As noted, we also only have data on business headquarters rather than more detailed data on the location of all business activity. We also do not have access to data on the actual output of solar systems by postcode.

A range of extensions are possible for future research. Analysis distinguishing between channels of peer influences for the non-residential sector could be interesting. Studies of uptake rates by government agencies and non-governmental organizations would also be of interest, as would studies of battery adoption, which is starting to take off in Australia. It would also be useful to examine the effect of premises leasing on business solar PV uptake rates; while a renter disadvantage has been observed in the residential sector (Best, 2022), it has yet to be carefully studied for the non-residential sector.

If available, analysis using data that apportion the employees or business operations of large firms across postcodes would be valuable to further understand the link between business size and distributed solar uptake by businesses. Future research could also potentially explore additional factors affecting non-residential uptake of distributed solar PV. This research could potentially consider awareness levels of solar PV among the non-residential sector and business-manager perceptions of rooftop solar PV.

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