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RESEARCH

Retrofit Poverty: Socioeconomic Spatial Disparities in Retrofit Subsidies Uptake

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Abstract

Framed in the concept of distributional justice, retrofit poverty may be understood as the inequality of opportunity to improve the energy performance of the home. Retrofitting existing homes may have substantial carbon-mitigation and cost-saving potential. Retrofit subsidies may increase energy improvement activities, raise awareness and lever market offers. However, there is concern about inequitable outcomes. This quantitative study used publicly available data sets to explore the socioeconomic and spatial distribution of the outputs of a market-based, white certificate programme for residential energy-efficiency improvements in the state of Victoria, Australia, between 2009 and 2017. Certificates signified avoided carbon emissions as a proxy for energy cost savings. Regression analyses combined data of certificate generation with socioeconomic indices, dwelling numbers and tenure characteristics at the postcode level. Areas with lower economic resources and higher shares of rented dwellings were statistically significantly associated with lower certificate generation intensity. As low-income households and renters feature highly in metrics of energy stress, the uneven distribution of benefits suggests that a utilitarian distributive subsidy approach may be regressive and (re)produce energy inequalities. A better understanding of the contexts, compositions and mechanisms that characterise retrofits is needed to develop socially equalising and effective policy tools.

Policy relevance

This paper addresses the distributive justice implications of residential energy-efficiency subsidies in Victoria, Australia. The relationships between white certificate generation intensities and variables that have been associated with energy hardship revealed inequities in the distribution of benefits. Lower outcomes in subsidy benefits in areas with low economic resources and high percentages of rented properties suggest that non-targeted financial incentives may be regressive and (re)produce energy inequalities. However, the data also suggest that the subsidy programme may have triggered a social normalisation of residential retrofit activities. Revealing retrofit scheme participation as a multidimensional issue with monetary, social and structural indicators, the study highlights that policies addressing the social impacts of low-carbon transitions must look to retrofit opportunity (dis)advantage. A restorative justice approach points to tailored retrofit-enabling schemes targeted at enhancing capabilities of vulnerable households, which may include targets for financially disadvantaged groups and setting minimum rental housing standards.

Keywords: climate justice; distributional justice; energy policy; equity; fuel poverty; housing; retrofit; white certificates; Australia

1. Introduction

> *Policies that succeed in mitigating [greenhouse gas] pollution should not do so in a way that worsens socioeconomic inequality.*
>
> (Granqvist & Grover 2016: 88)

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The Paris Agreement (United Nations 2015) highlights two key challenges in the transition to a lower carbon future: the need for a speedy and large-scale adoption of technological innovations, and the moral imperative to protect vulnerable population groups. Retrofitting the existing housing stock is an important tool in agendas to pursue low-carbon transitions and tackle challenges of equity (Lucon *et al.* 2014). In particular, the thermal performance and efficiency of housing is central to efforts to address issues of energy poverty, particularly in the Global North (Boardman 2012; Bouzarovski & Petrova 2015). Yet, there are concerns that policies and programmes aimed to improve the quality of existing homes are not reaching those most in need, and that, if poorly targeted and funded, they might exacerbate already existing dynamics of disadvantage and cumulative vulnerabilities of housing affordability stress (Baker, Lester, Beer, & Bentley 2019; Middlemiss & Gillard 2015; Moser 2013).

The aim of this paper is to test and advance the term 'retrofit poverty' as the inequality of opportunity to improve the energy performance of the home. Within the context of low-carbon energy transitions, this concept addresses the challenge to balance climate change mitigation outcomes and equity (Klinsky & Dowlatabadi 2008; Klinsky *et al.* 2017). Retrofits are understood as any material measures that may lower energy consumption and costs or enhance thermal comfort. Activities may improve the thermal efficiency of the building envelope, upgrade lighting, space conditioning appliances and white goods, and include low-carbon electricity microgeneration, such as the installation of solar photovoltaic (PV) systems (Willand & Horne 2013).

The paper supports previous work showing that retrofit policy tools that rely on market-based mechanisms and assume householders as empowered actors, may be regressive (Rosenow 2012; Rosenow, Platt, & Flanagan 2013). Furthermore, it responds to calls for analyses of manifestations of energy justice as 'deeply geographical' phenomena and how they may be compounded by energy transition initiatives (Bouzarovski & Simcock 2017: 643). While area or place-based approaches are increasingly advocated to examine the links among social, health, energy and housing inequities (Badland & Pearce 2019; Bouzarovski & Simcock 2017), research that explores the spatial coverage of subsidies to improve dwellings is rare. However, such investigations can contribute to a better understanding of low-energy transition outcomes in terms of distributional equity, identify key attributes that seem to heighten unfairness, inform policies to redress these and recommend future research. This study begins to address these points. It is framed within the concept of distributional equity, focusing on the conditions that may restrict the capability to retrofit. The primary question of this value-informed study was: Is there evidence that retrofit subsidies in the Australian state of Victoria may compound existing socioeconomic inequalities? Presenting a spatial analysis of the Victorian Energy Upgrade (VEU) programme, this study empirically tests the relationship between residential retrofit subsidy benefits and variables that have been associated with manifestations of energy hardship. It introduces the term 'retrofit poverty' as a less researched dimension of the nexus between housing condition, energy equity and low-carbon futures, and contributes to better knowledge of retrofit participation.

The paper is structured as follows. The next section presents background information on the concept of distributional equity, Energy Efficiency Obligation (EOO) schemes and the VEU programme. The third section describes the data sources and main variables used in the statistical tests. The fourth section reports on the assessment of distribution of benefits between metropolitan and regional areas, and across socioeconomic and tenure characteristics of postcode areas within the state. The fifth section evaluates the findings for equity and summarises limitations of our study. The sixth section summarises the main argument and reflects on its policy implications.

2. Background

2.1. Conceptual framework

Based on the idea that low-carbon transition policies should engage with moral reasoning (Granqvist & Grover 2016; United Nations 2015; WCED 1987), this paper links the capability approach to questions of equity in an Energy Efficiency Obligations (EOO) programme. Considerations about equity address the social dimension of sustainable developments, which is based on the premise that people should lead a good and fulfilling life and that avoidable differences should be removed (WCED 1987). Assessing the ethical implications of energy policies is relevant in the context of energy poverty as a risk to health and well-being and global efforts to reduce distributional inequalities (United Nations 2019). The analysis of (in)equalities may focus on the distribution of resources, opportunities or outcomes (Burchardt & Hick 2017). This study follows the approach of Day, Walker & Simcock (2016), who have placed a capabilities framework as central to a broader view of energy inequality and advanced the theoretical foundation of strategies that aim to recognise and ameliorate energy deprivation. Hence, this paper explores to what extent known factors of energy deprivation and constraints in the capability to retrofit are associated with the distribution of benefits of retrofit subsidies and how energy policies may result in more equitable outcomes.

The capability approach, as developed by the economist and philosopher Amartya Sen, offers a 'framework for the evaluation and assessment of individual well-being and social arrangements, the design of policies, and proposals about social change in society' (Robeyns 2005: 93). Capabilities are opportunities that allow people to do or be things, so-called functionings, and to achieve a good quality of life (Robeyns 2005; Sen 1990). As capabilities are positively linked to freedom and autonomy, constraints in enacting functionings equate to limited capabilities. Analyses of equality may focus on thresholds or distributional inequality and explore horizontal comparisons between groups or vertical comparisons within groups or populations (Burchardt & Hick 2017).

Energy poverty or inequality has no single definition, but can be understood as the lack of access to affordable, renewable and reliable essential energy services (Bouzarovski 2013; Thomson, Bouzarovski, & Snell 2017; United Nations 2019). Day *et al.* (2016) argued that energy inequality is more than a symptom of low income. Causes may include energy-inefficient dwellings and restricted choice in energy supply. They suggest that interventions should address the multidimensionality of conditions that shape deprivation. The present paper focuses on the capability or opportunity to retrofit the home. Retrofitting the home may be regarded as a functioning to reduce energy costs, increase comfort and improve health (Willand, Ridley, & Maller 2015). Constraints in retrofitting may be financial in nature, such as low discretionary income, or have structural causes, such as the lack in agency among renters.

Central to this paper is the aspect of fairness in the design of energy-transition policies. In particular, it addresses distributional (in)equity of subsidy benefits, which implies a moral value judgement of the extent of distributional (in)equality. Distributional (in)equality reflects the pattern of the distribution of resources, benefits and burdens across populations and space. Relevant approaches to distributive equality of resources are strict egalitarianism, which is the even distribution across all parties, utilitarian equality, which aims to maximise the desired outputs, and the principle of democratic equality, which advocates for raising valued outcomes for disadvantaged parties (Hillman 2004). In line with the quotation at the start of this paper, our argument is guided by the fairness criterion that the political management towards a lower carbon society should be progressive in the sense that it reduces the level of energy-related socioeconomic disadvantage in a society and leads to more even outcomes in well-being (Granqvist & Grover 2016).

2.2. Energy Efficiency Obligations (EOOs)

Retrofitting in owner-occupied-dominated, lightly regulated housing policy jurisdictions is largely a voluntary, private, self-driven and often costly activity (Willand & Horne 2013). In this context, EEOs are market-based policy instruments that encourage the uptake of energy-efficiency improvements through subsidies. Energy-reduction targets are placed on organisations such as energy utilities, which then discount retrofit activities to achieve these goals (Fawcett, Rosenow, & Bertoldi 2019). Notwithstanding the variety in designs, the costs of the EEOs are often passed from the energy utilities onto consumers through bill surcharges (Rosenow, Cowart, & Thomas 2019).

EEOs are used in over 50 jurisdictions worldwide (Rosenow *et al.* 2019), and they are expected to become more widespread (IEA 2017). They are popular as they allow flexibility in delivery and place minimal financial burdens on governments (IEA 2017; Rosenow & Bayer 2017). They have also successfully promoted private consumer investment in energy-efficiency measures (Rosenow *et al.* 2019). However, EOOs may also support free-riders, *i.e.* participants who are able and willing to pay and who would not have needed subsidies. Free-ridership may be interpreted as a market failure and an expression of an unequitable distribution of EEO benefits (Fawcett *et al.* 2019; Rosenow *et al.* 2019).

EEOs may provide distal social benefits, such as avoided energy infrastructure upgrade costs and better air quality (Rosenow *et al.* 2019). Participating householders may also experience better thermal comfort and increased asset values. Participants may also gain financially, when the costs savings due to the retrofits exceed the apportioned cost burdens of the scheme (Rosenow & Bayer 2017). Cost savings may be negated, however, when potential financial benefits are traded for improved comfort or undermined by changes in energy practices (Fawcett *et al.* 2019; Rosenow *et al.* 2019). Such rebound and pre-bound effects are frequently observed in low-income and fuel-poor households (Galvin 2015; Sunikka-Blank & Galvin 2012; Teli *et al.* 2016), and may challenge the estimation of deemed savings in emissions (Rosenow *et al.* 2019).

Green certificates are a similar market-based policy tool. Whereas white certificates aim to reduce energy demand, green certificates seek to accelerate the decarbonisation of the electricity supply by providing financial incentives to install solar PV systems and other renewable microgeneration systems. Owing to the reallocation of costs to consumers, there are concerns that market-based policy tools such as white and green certificate programmes may be regressive for non-participants (IEA 2017). Common mitigation measures are targets for low income, most notable the 100% objective in the UK (Rosenow *et al.* 2019). Other strategies that promise more equitable distributions of costs and benefits across households allocate costs only to households who can bear the burden, or provide low-income households with income support to balance the surcharges (Granqvist & Grover 2016).

2.3. Case study: The Victorian context

Victoria is Australia's second most populous state (ABS 2019b), with three-quarters of its inhabitants living in its capital, Melbourne, and a relatively high population growth rate, which is driving housing demand. Responses include high-rise developments in the city centre, higher density housing in the inner suburbs and new developments in outer suburbs with predominantly detached houses. As inner-city suburbs are experiencing gentrification (Buxton, Goodman, & Moloney 2016), lower income families are pushed out onto the periphery (Lim 2018). The growth in coastal and regional areas is amplified by older Melbournians retiring to their second or more affordable homes (Luck, Race, & Black 2010; Saberi *et al.* 2017).

In Australia, policies aiming to improve the energy performance of homes have focused on new housing and the setting of minimum performance requirements (Moore, Horne, & Morrissey 2014). However, as retrofits of the existing housing stock have the potential to achieve substantial reductions in energy emissions and costs, they are promoted by national and state governments (COAG Energy Council 2018; Sustainability Victoria 2015; Victorian Government, Department of Economic Development, Jobs, Transport and Resources 2015). Market-based mechanisms are favoured (COAG Energy Council 2018). In contrast to European countries, which are obliged to address energy inequalities in their climate change-mitigation initiatives (European Commission 2019), in Australia there is little governmental commitment to alleviate energy hardship. Nonetheless, the need to make provisions for low-income householders has been acknowledged (COAG Energy Council 2018).

Low-income and rental households in Australia are at a higher risk of energy stress than wealthier population groups and owner-occupiers (ACOSS & Brotherhood of St Laurence 2019; Colmar Brunton 2018; Poruschi & Ambrey 2018). Renters are also more likely to lack energy-efficiency features that are common in owner-occupied dwellings (ABS 2010; Colmar Brunton 2018; Energy Consult 2009). While restrictions in tenant agreements prevent renters from making material changes to the property without the consent of their landlord (Acil Allen Consulting 2018), profit-driven landlords may lack the motivation to invest in energy-efficiency measures as demand for rental properties exceeds supply (AHURI 2017). Renters may also have little knowledge or understanding of the energy performance of their home or interest in this matter (Pitt & Sherry 2014; QCOSS 2017). In response, community services and advocacy organisations in Victoria have joined in a call for political action to protect renters through mandatory housing standards (ACOSS & Brotherhood of St Laurence 2018). These would translate into retrofit obligations for existing, rented homes.

White and green certificates are also common policy tools designed to promote retrofit in Australia. White certificate schemes operate at the state level, *e.g.* in Victoria, through the VEU programme and the Energy Efficiency Improvement Scheme in the Australian Capital Territory (ACT). Green certificates are generated through the Small-Scale Renewable Energy Scheme (SRES), which offers grants for solar PV systems to householders and businesses on a national scale (Clean Energy Regulator 2018). In contrast to the UK (Rosenow *et al.* 2013), in Australia, white and green certificates are not used to address energy inequality (Hillman 2004; Walker 2012). The VEU programme and SRES pursue the distributive principle of utilitarian equality. They aim to achieve the maximum in carbon emission reductions by focusing on opportunities inherent in the material characteristics of dwellings and treating all households as equal. The ACT's scheme, however, takes a democratic equality approach by setting targets for activities in 'priority households', which are low-income private, public and community housing renters on energy retailers' hardship programmes (ACT Environment Planning and Sustainable Development Directorate 2019).

2.4. The spatial dimension of retrofits

The concept of retrofit poverty offers a framework for exploring the socioeconomic, demographic and spatial dimensions that shape the opportunities to improve residential energy outcomes. While much of the work hitherto has focused on disparities in the functionings of affording energy or achieving adequate indoor temperatures in Europe (Burholt & Windle 2006; Healy 2004) and in Australia (Baker *et al.* 2019), interest in the spatial distribution of intervention benefits is emerging (Bouzarovski & Simcock 2017). European research suggests that regional polarisation may lead to disparities in retrofit projects and subsidies, with metropolitan regions benefiting more than peripheral areas (Bouzarovski & Tirado Herrero 2017; Lihtmaa, Hess, & Leetmaa 2018; Turcu 2016). In Australia, investigations into the spatial distribution of low-carbon technology uptake have focused on solar PV installations (Best, Burke, & Nishitateno 2019; Chandrashekeran & Li 2019). In this study, we undertook geographical research on retrofit subsidies to provide a better understanding of the mechanisms that shape the capabilities needed for retrofitting and to reveal inequalities of opportunities to reduce energy costs and emissions.

2.5. Victorian Energy Upgrade (VEU) programme

The VEU is a market-based retrofit subsidy programme launched by the Victorian government in 2009 in order to reduce greenhouse gas emissions (Victorian Parliament 2007). It also aims to promote the introduction of new products and investment in the retrofit service sector and to create jobs (DELWP 2019; Victorian Parliament 2007). Retrofit activities cover residential and commercial buildings. The primary outcome of the VEU is measured in Victorian Energy Efficiency Certificates (VEECs). These represent the activities' potential savings in carbon dioxide equivalents (CO_2-e). One VEEC represents 1 tonne of avoided CO_2-e. Annual targets range between 2.7 million and 6.5 million certificates (ESC 2020). The VEECs of each VEU programme activity reflect the avoided emissions of the energy-related service that is addressed and, hence, vary among the various VEU programme activities. The Victorian government attributes the state's flattening energy demand and the availability of affordable, efficient lighting products to the VEU (DELWP 2019). The VEU is also estimated to have created more than 2000 jobs (DELWP 2019). The programme will continue until 2029.

The residential activity sector of the VEU offers activities in 11 categories which include appliance upgrade options and provision of convenience and electricity consumption feedback tools for houses, apartments and hotels. Some VEEC activities, such as the upgrade of tungsten bulbs and halogen lights to LED lamps, low-flow shower roses and stand-by power controllers are offered to householders free of charge. All other activities require financial co-contributions by householders. Activities are implemented by service providers and require householder signatures as evidence. **Table 1** presents a list of these categories, the relevant activities (ESC 2017, 2019) and the abbreviations used for the categories in the diagrams of the Results sections.

Table 1: Victorian Energy Upgrade (VEU) programme categories and associated activities.

Category (abbreviation)	Activity type
Water Heating (WH)	Replacement of an electric water heating system with more efficient systems, *e.g.* gas/liquefied petroleum gas (LPG) storage or gas/LPG instantaneous or electric-boosted solar or gas/LPG-boosted solar systems; solar retrofit kit for existing water heating system
Space Heating & Cooling (SHC)	High-efficiency ducted gas heating system replacing an inefficient gas-ducted heating system or a central electric heater; installation of ducted air heat pump, replacement of refrigerative air-conditioner with ducted evaporative cooler; gas ductwork replacement
Space Conditioning (SC)	Ceiling and underfloor insulation; window replacements or retrofits; draught proofing
Shower Rose (SR)	Replacement with a water-efficient shower rose
Refrigerator or Freezer (Fr)	Decommissioning of an inefficient and purchase of an efficient refrigerator or freezer
Lighting Replacement (Light)	Replacement of inefficient light bulbs with more efficient ones
Television (TV)	Installation of a highly efficient television
Clothes Dryer (CD)	Installation of a highly efficient clothes dryer
Pool Pumps (PP)	Installation of a highly efficient pool pump
SPCs (SPC)	Installation of stand-by power controllers
IHDs (IHD)	Installation of in-home display units

Although VEECs primarily reflect avoided carbon emissions, they may also be interpreted as a proxy for energy costs savings. VEECs may directly equate to potential savings in energy costs when the activity does not involve a fuel change, *e.g.* in lighting upgrades. VEECs from activities that involve a fuel change save more energy costs than VEECs without a switch in fuel type. For example, the switch from an electric water heating system to a gas or solar-powered device reduces energy costs substantially as gas or solar electricity unit costs are lower than electricity from the grid. However, such fine differentiation or the estimation of exact savings in energy expenditure was outside the scope of this study.

3. Methods

The study tested the relationship between residential retrofit white certificates and variables that have been associated with manifestations of energy hardship. It was conducted to the spatial unit of four-digit postcodes and used regression models to investigate the links between indices of economic resources, social (dis)advantage and tenure. Spatial disparities in the uptake to retrofit subsidies may point towards social inequities in retrofit services or contextual conditions.

3.1. Data sources

The study used open-source data from the Register of Victorian Energy Efficiency Certificates (ESC 2019) and Census data from the Australian Bureau of Statistics (ABS) (2013b, 2018). It focused on the VEU residential activities from its launch in 2009 until the end of the financial year in June 2017.

3.2. Key variables

The variables of primary interest were the intensity of VEECs generation as the dependent or outcome variable, and socioeconomic scores and prevalence of tenure as the independent or predictor variables. A differentiation into metropolitan and regional postcode areas served to test the relative (dis)advantages of location and economic geography. Calculation of indicators was performed in the spreadsheet software Microsoft Excel 2016. Statistical analyses were conducted in the software IBM SPSSv26, and geographical mappings of outcome variables in the data-visualisation software Tableau 2019.1.

Following previous research (Sullivan & Johnson 2012), VEECs generation intensity was defined as the number of residential VEECs generated for every 100 private dwellings (Equation 1). The numbers of private dwellings were derived from the ABS Census 2016 data and included occupied and unoccupied dwellings. This normalisation of VEECs generation allowed for the comparison of VEEC outputs across locations with varying dwelling numbers:

$$\text{VEECs generation intensity} = \frac{\text{Total number of VEECs generated}}{\text{Number of all private dwellings in Census 2016}} * 100$$

The main variables representing the areas' socioeconomic levels were the SEIFA IER and SEIFA IRSAD scores. Socio-Economic Indexes for Areas (SEIFA) scores are calculated by the ABS based on the latest census data and area weighted variables (ABS 2013a). The Index of Economic Resources (IER) combines financial variables such as income and wealth. The Index of Relative Socio-Economic Advantage and Disadvantage (IRSAD) captures a more general level of 'people's access to material and social resources, and their ability to participate in society' (ABS 2013a: 3). Changes in these indices since the 2011 Census were calculated to reflect levels of gentrification.

Tenure prevalence was expressed as the rate of rented dwellings, *i.e.* the percentage of occupied dwellings in each postcode area that were rented on the Census 2016 night. The allocation of postcode areas to metropolitan and regional locations followed the characterisation of areas in the Register of Victorian Energy Efficiency Certificates.

4. Results

The analysis was based on 689 Victorian postcodes, 275 in metropolitan and 414 in regional Victoria, for which valid VEECs generation intensity could be calculated. These areas presented 2.39 million dwellings, 72% of which were in the metropolitan region. A total of 21 Victorian postcodes that did not present any occupied dwellings in the 2016 Census were excluded. In one additional area, the normalisation of VEECs generation revealed one postcode area in which 97% of VEECs had been generated from stand-by power controllers. This unusual distribution of VEECs by activities was explained by the building stock mixture of several hotels and very few dwellings. As this area did not have any SEIFA scores, this postcode was also excluded in the subsequent analyses. One extreme outlier with almost four times the next highest VEECs generation intensity was removed, although the share of certificates by activities was typical. A check by the VEU programme administrator revealed that VEEC claims had been misallocated to this postcode as surrounding postcode areas had not been listed in the registry. The exclusions removed 0.06% of all VEECs.

4.1. Descriptive statistics and independent sample t-tests

This analysis covered more than 3.5 million activities and more than 33.4 million VEECs or tonnes of avoided CO_2-e. The VEECs generation was dominated by lighting upgrades and stand-by power controllers. Together with shower roses, these free activities accounted for 84% of all white certificates (**Figure 1**). The total counts of VEECs varied considerably between metropolitan and regional parts of the state and among postcode areas. The number of VEECs generated in metropolitan Melbourne (69%) was more than double the number generated in regional Victoria (31%) (**Figure 2**). The mean number of VEECS per postcode area across the whole state was 48,504 certificates, with both the lowest (four VEECs) and highest counts (555,326 VEECs) found in metropolitan areas. On average, metropolitan postcode areas generated more than three times the number of certificates than regional areas (**Table 2**).

However, when the numbers of certificates in the two locations were normalised to 100 dwellings, the intensity of VEECs generation was lower in the metropolitan areas (1343 VEECs per 100 dwellings) than in regional Victoria (1540 VEECs per 100 dwellings) (**Figure 3**). In metropolitan areas, relatively more VEECS were generated from lighting upgrades than in regional areas (57% and 38%, respectively). By contrast, in regional Victoria, water heater upgrades accounted for a larger share of VEECs than in metropolitan Melbourne (21% and 3%, respectively). The mean VEECs generation intensity per postcode area across the whole state was 1506 certificates for every 100 dwellings, with the lowest intensity (4 VEECs per 100 dwellings) found in the metropolitan area and the highest intensity (3545 VEECs per 100 dwellings) in regional Victoria (**Table 3**).

The spatial mapping of the VEECs generation intensity (**Figure 4**) showed that most areas presented intensities just below the mid-value. Area clusters or neighbourhoods with similarly high VEECs generation intensities were revealed along the Murray River at the northern boundary of the state, west of Geelong and towards Lakes Entrance. Cold spots were isolated and included a military base with almost exclusively rented dwellings, and French Island in the Bass Strait with limited accessibility. Within the metropolitan area, the city centre with its new residential skyscrapers and the new suburbs in the south-east presented areas with low VEECs generation intensity. High intensities were found north-west of the city and along the main roads leading to the Mornington Peninsula (**Figure 5**).

At the postcode level, mean VEECs generation intensity in regional Victoria was 16% higher than in metropolitan Melbourne, a difference that was statistically significant (**Table 4**). The calculation and mapping of the share of the certificates that had been generated from the free activities in each postcode (**Figure 6**) showed that these activities accounted for more than half of all VEECs in most areas. A high share cluster was apparent in and around Melbourne. On average, the share of the certificates that had been generated from free activities was 25% higher in metropolitan areas (87%) than in regional areas (62%). This difference was highly statistically significant. At the postcode level, the mean VEECs generation intensity from the predominant free activity of lighting upgrades was 14% higher in metropolitan than in regional areas. By contrast, the mean VEECs generation intensity from water-heating upgrades, the predominant activity requiring a financial contribution by householders, was five times higher in regional areas (**Table 4**).

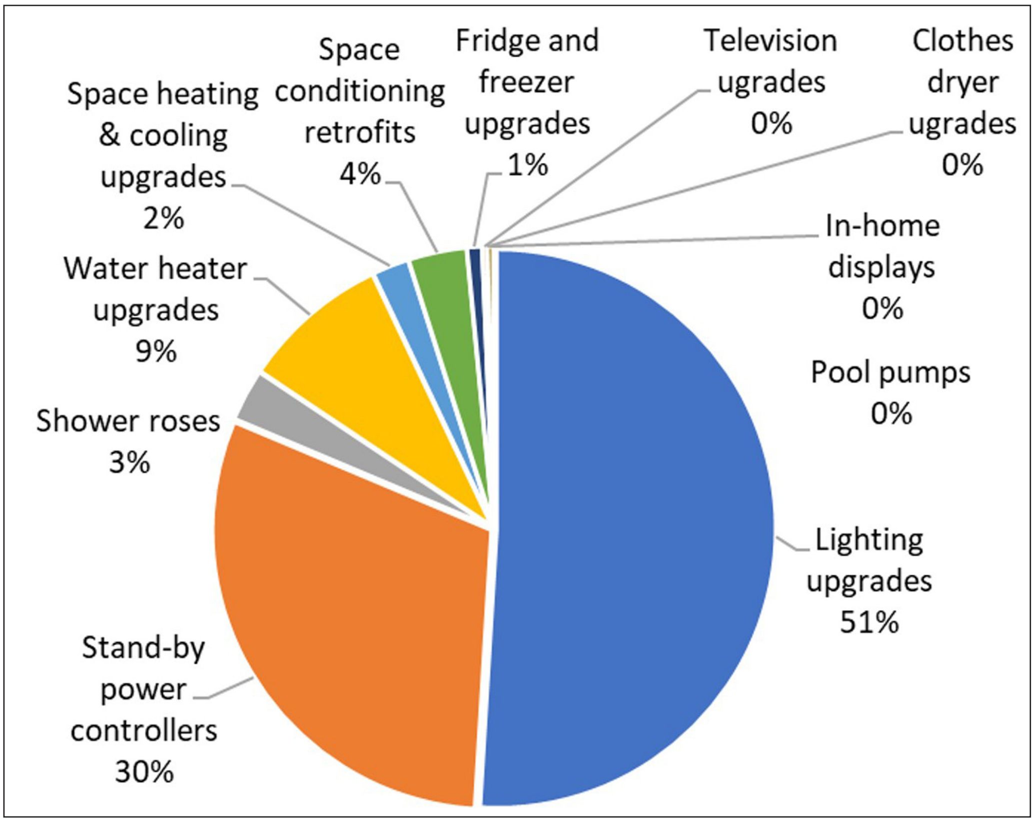

Figure 1: Distribution of Victorian Energy Efficiency Certificates (VEECs) by categories of activities.

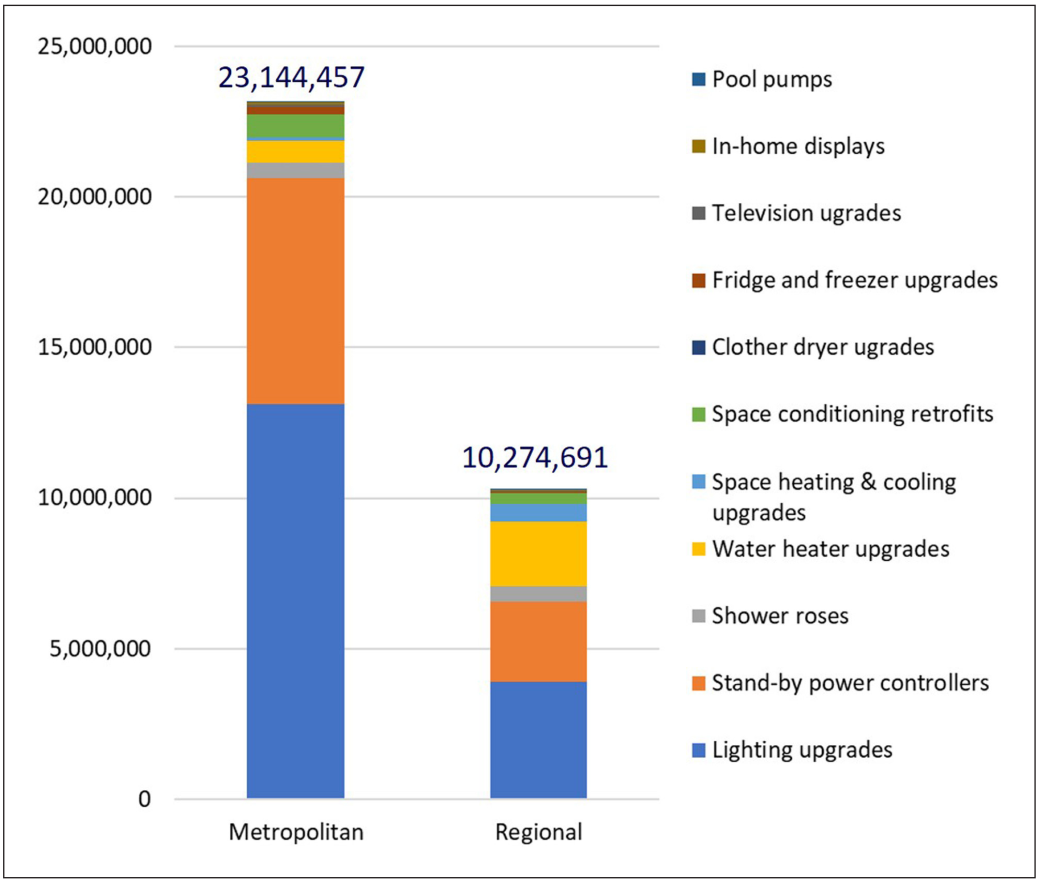

Figure 2: Comparison of the number of Victorian Energy Efficiency Certificates (VEECs) generated in metropolitan and regional areas.

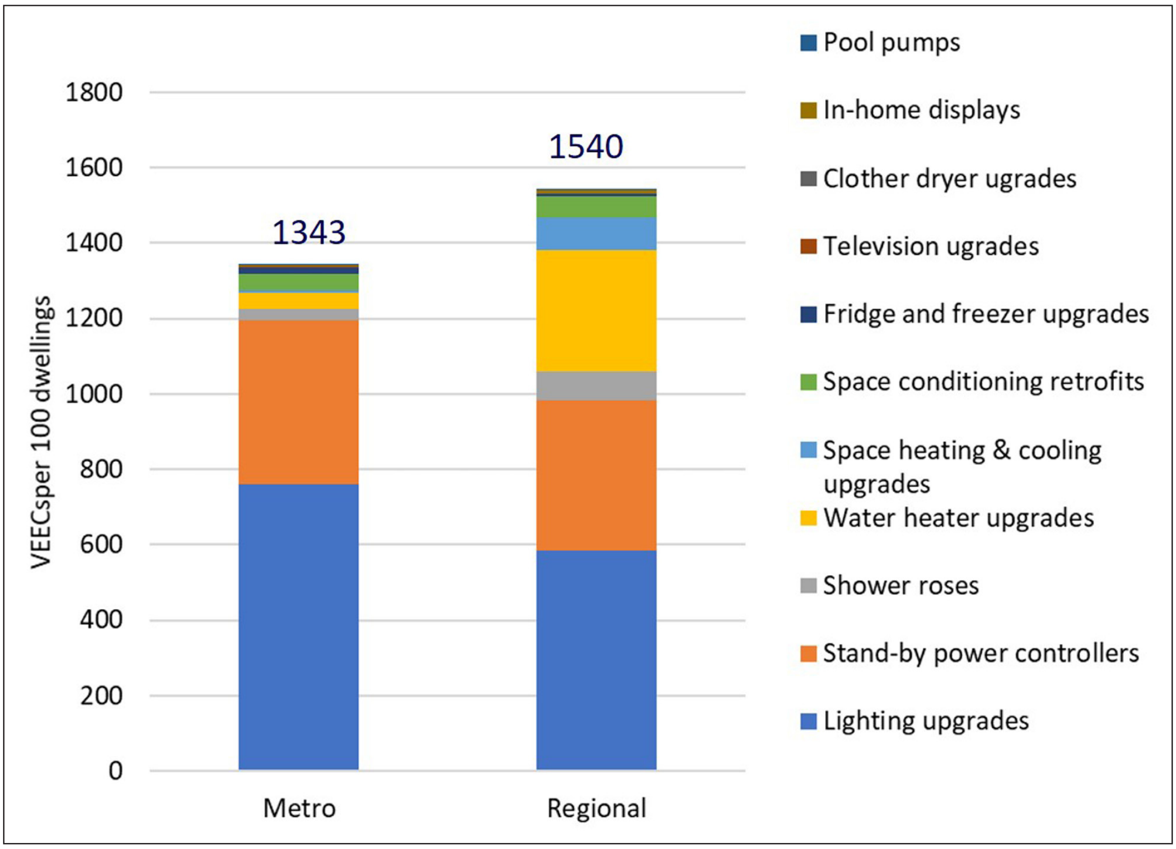

Figure 3: Comparison of Victorian Energy Efficiency Certificate (VEEC) generation intensity by categories in each location.

Table 2: Descriptive statistics for Victorian Energy Efficiency Certificate (VEEC) generation: total number of VEECs.

Variable	*N*	Mean	SD	Minimum	Maximum
All postcode areas	689	48,503.84	70,746.93	4	555,326
Metropolitan areas	275	84,161.66	86,644.53	4	555,326
Regional areas	414	24,818.09	44,138.73	23	360,964

Table 3: Descriptive statistics for dwelling numbers and Victorian Energy Efficiency Certificate (VEEC) generation intensity.

Variable	*N*	Mean	SD	Minimum	Maximum
Number of occupied and unoccupied private dwellings					
All postcode areas	689	3468.86	4787.51	9	34,581
Metropolitan areas	275	6265.35	5600.43	12	34,581
Regional areas	414	1611.29	2950.79	9	25,403
Total number of VEECs per 100 dwellings					
All postcode areas	689	1505.92	489.59	4	3545
Metropolitan areas	275	1370.80	462.21	4	2630
Regional areas	414	1595.68	487.18	22	3545

4.2. Linear regression analyses

Linear regression models were calculated to test the association of VEECs generation intensity and the socioeconomic and tenure variables. The mean 2016 IER and IRSAD were significantly higher, but presented a larger distribution in metropolitan than in the regional areas. The mean changes in SEIFA scores between 2011 and 2016 were positive in both locations, but on average higher in regional than in metropolitan areas. The proportion of rented dwellings was significantly higher in metropolitan than in regional areas; the inverse was true for the rate of unoccupied dwellings (**Table 5**).

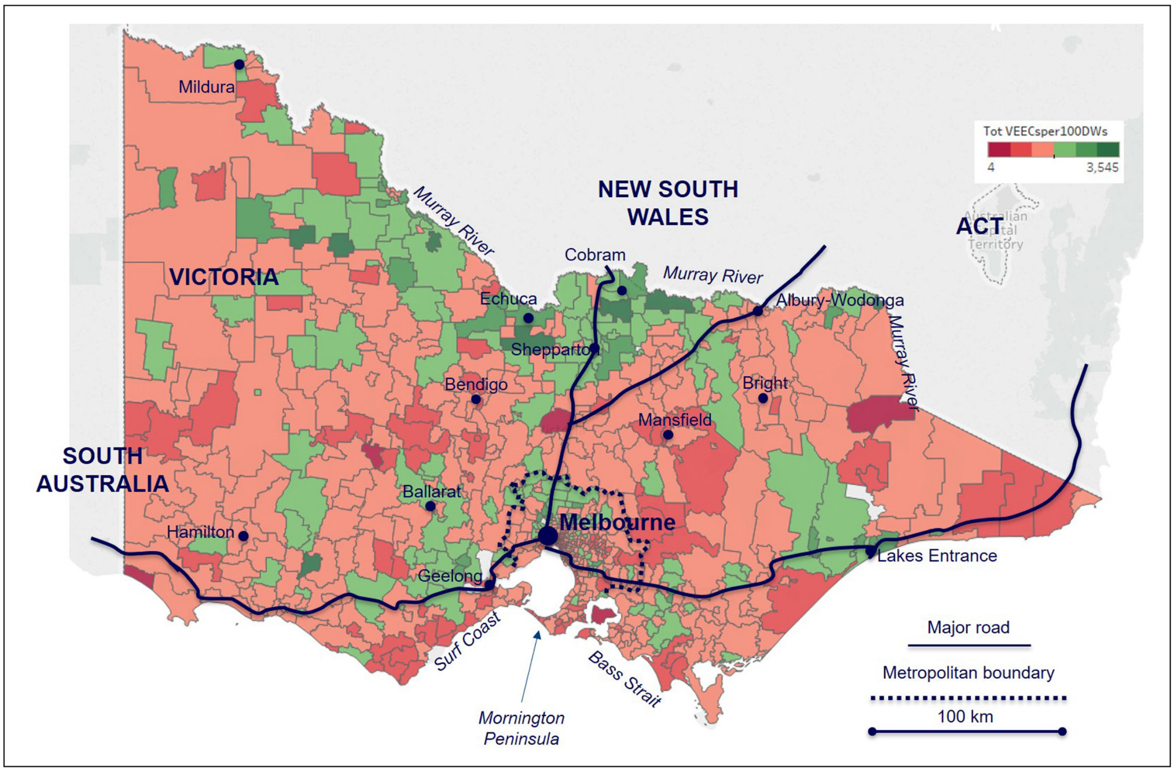

Figure 4: Spatial mapping of Victorian Energy Efficiency Certificate (VEEC) generation intensity per dwelling. Also shown are the major state highways and main towns.

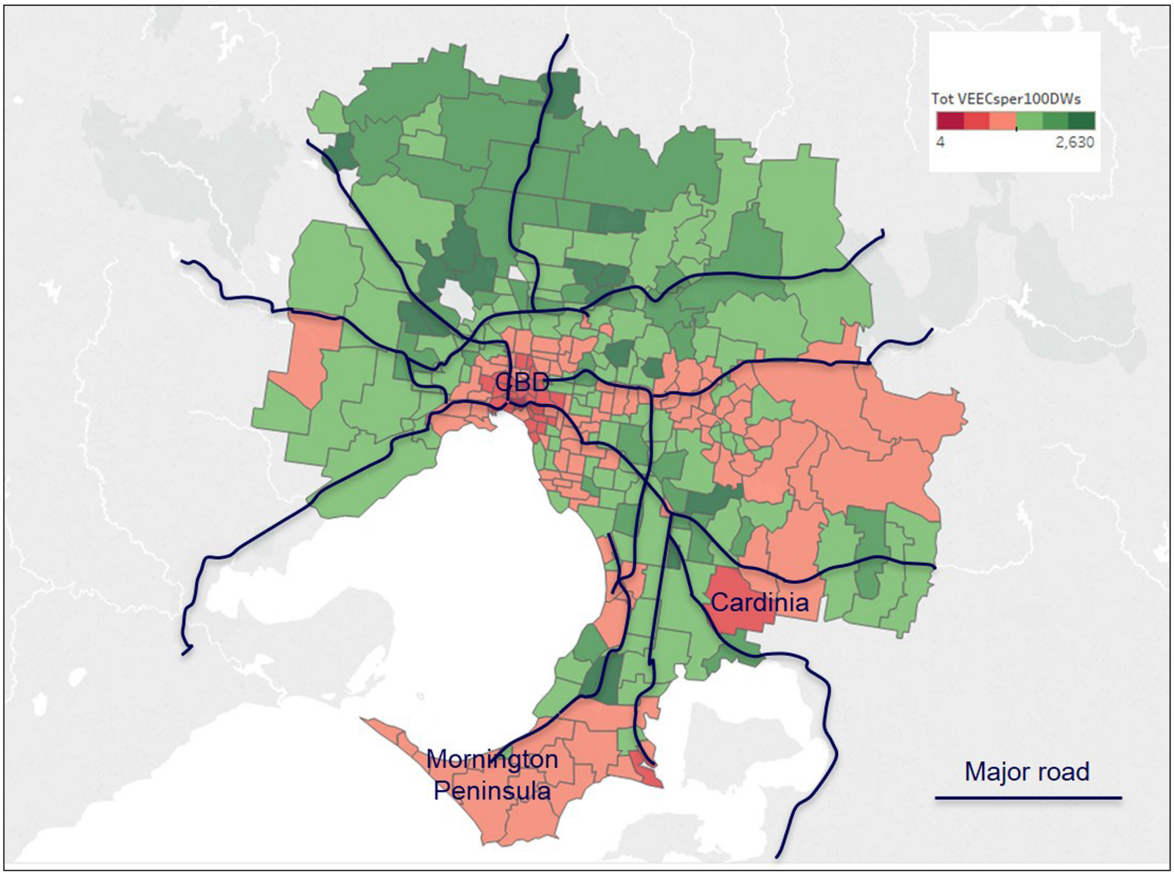

Figure 5: Spatial mapping of Victorian Energy Efficiency Certificate (VEEC) generation intensity per dwelling: all metropolitan postcode areas.

Table 4: Independent samples *t*-test results of Victorian Energy Efficiency Certificate (VEEC) generation intensity by location.

Variable	Group statistics			*t*-test for equality of means			Mean difference
	N	**Mean**	**SD**	***t***	**d.f.**	***p***	
VEECs generation intensity							
Metropolitan areas	275	1370.80	462.21	–6.06	687	2.30E–09**	–224.89
Regional areas[a]	414	1595.68	487.18				
Share of VEECS from free activities (lighting upgrades, shower rose replacements, installation of stand-by power controllers)							
Metropolitan areas[a]	275	0.87	0.09	31.43	681	1.10E–134**	0.25
Regional areas[a]	414	0.62	0.12				
VEECs generation intensity of lighting upgrade activities							
Metropolitan areas	275	748.78	330.78	9.24	409	1.42E–18**	205.64
Regional areas[a]	414	543.14	201.40				
VEECs generation intensity of water heating upgrade activities							
Metropolitan areas	275	89.41	115.98	–25.50	611	3.05E–98**	–374.48
Regional areas[a]	414	463.90	262.78				

Notes: [a] Levene's test of homogeneity of variance indicated that equal variance could not be assumed.
** Highly statistically significant at $p < 0.001$.

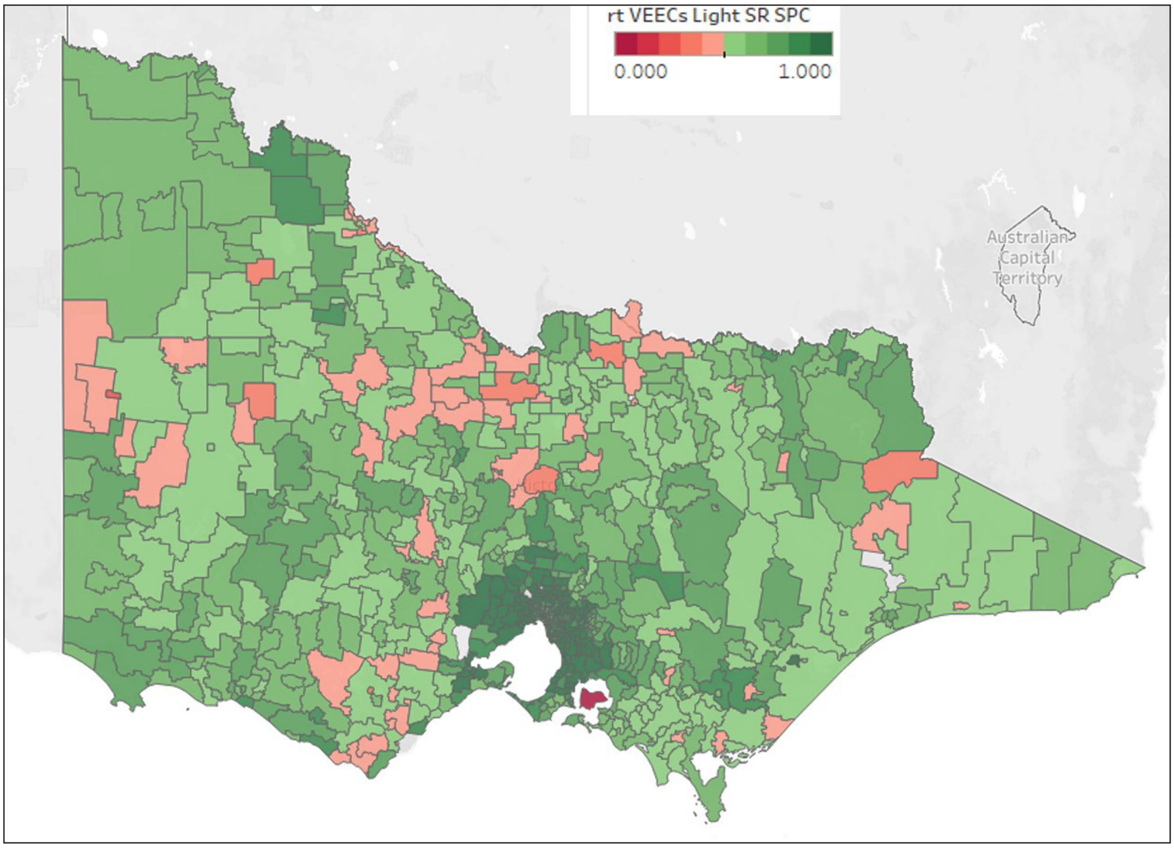

Figure 6: Spatial mapping of share of Victorian Energy Efficiency Certificates (VEECs) generated from the free activities of lighting upgrades, shower roses and stand-by power controllers.

Highly statistically significantly positive associations of VEECs generation intensity across all postcode areas were observed for the 2016 IER scores and their change since 2011. The rates of rented homes and unoccupied dwellings were negatively associated with VEECs generation intensity at the 0.0001 level. The relationships between the variables of IER and prevalence of rented dwellings and VEECs generation intensity were stronger in metropolitan areas than in regional areas. The very low *p*-values in many of the tests meant that the sample provided good evidence of an association between the predictor and the outcome variables (**Table 6**).

Table 5: Descriptive statistics for predictor variables with the results of an independent samples *t*-test to assess the difference in means between metropolitan and regional postcode areas.

	N	Mean	SD	Minimum	Maximum	*t*-test for equality of means			Mean difference
						t	d.f.	*p*	
SEIFA IER score, 2016									
All postcode areas	672	1011.23	57.09	731.00	1168.00				
Metropolitan areas	269	1023.41	70.24	731.00	1168.00	4.21	411.51	3.10E–05**	20.31[a]
Regional areas	403	1003.10	44.56	846.00	1112.00				
SEIFA IRSAD score, 2016									
All postcode areas	672	1006.57	59.69	783.00	1126.00				
Metropolitan areas	269	1036.89	62.57	783.00	1126.00	11.23	471.84	4.36E–26**	50.57[a]
Regional areas	403	986.32	48.06	795.00	1097.00				
Change in SEIFA IER score, 2011–16									
All postcode areas	672	2.57	14.83	–58.62	83.74				
Metropolitan areas	269	1.09	13.49	–58.62	71.62	–2.17	627.18	.030*	–2.46[a]
Regional areas	403	3.55	15.61	–39.33	83.74				
Change in SEIFA IRSAD score, 2011–16									
All postcode areas	672	8.64	19.03	–62.88	110.51				
Metropolitan areas	269	3.29	18.51	–62.88	110.51	–6.12	670.00	1.57E–09*	–8.93
Regional areas	403	12.22	18.54	–61.01	96.20				
Rate of rented, occupied dwellings, 2016									
All postcode areas	689	0.22	0.13	0.00	1.00				
Metropolitan areas	275	0.27	0.16	0.03	1.00	7.83	372.21	5.14E–14**	0.08[a]
Regional areas	414	0.18	0.08	0.00	0.98				
Rate of unoccupied dwellings, 2016									
All postcode areas	689	0.16	0.13	0.00	0.87				
Metropolitan areas	275	0.11	0.11	0.00	0.87	–9.92	650.33	1.10E–21**	–0.09[a]
Regional areas	414	0.20	0.13	0.00	0.78				

Notes: [a] Levene's test of homogeneity of variance indicated that equal variance could not be assumed.
SEIFA IER = Socio-Economic Indexes for Areas Index of Economic Resources; and SEIFA IRSAD = Socio-Economic Indexes for Areas Index of Relative Socio-Economic Advantage and Disadvantage.

The disaggregation of certificate intensities into the predominant activities of lighting and water heater upgrades (**Tables 7** and **8**, respectively) concurred that economic resources were a stronger predictor of VEECs intensities in metropolitan than in regional areas. Relative socioeconomic advantage predicted higher VEECs generation intensities from free lighting activities in regional, but not in metropolitan, areas. The reverse was found for VEECs intensities from water-heating activities that required householder co-payments, which were associated with relative socioeconomic advantage in Melbourne, but not in regional Victoria. Increases in wealth and socioeconomic advantage predicted higher VEECs generation intensity from water heating upgrades across metropolitan, but not in regional, areas. The prevalence of rented dwellings negatively predicted the VEECs generation intensity from free lighting upgrades in metropolitan, but not in regional, areas. There was a negative association between the VEECs generation intensity from water heater upgrades and the rate of rented dwellings for both location groups.

4.3. Multiple regression analyses

A multiple regression was run to predict the VEECs generation intensity from the postcode areas' prevalence of rented homes and share of unoccupied dwellings. The areas' SEIFA IER scores were not included because of their negative correlation with the areas' share of rented homes (r = –0.621). The rates of rented homes and of unoccupied dwellings highly statistically significantly predicted the VEECs generation intensity ($F(2, 688) = 88.821$, p = 4.98E–35) and explained 20.6% of the variance (**Table 9**). Within the metropolitan region, these two factors explained almost half the VEECs generation intensity ($F(2, 274) = 130.506$, p = 1.84E–40, $r^2 = 0.49$) (**Table 10**). This suggests that renters in metropolitan Melbourne were at a higher risk of missing out on retrofit subsidies than owner-occupiers.

Table 6: Results of the linear regression model predicting the effect of the dependent variables on Victorian Energy Efficiency Certificate (VEEC) generation intensity, differentiated by location.

Variable	r^2	ANOVA		Unstandardised coefficients			95% confidence interval for β	
		d.f.	F	β	Constant	p	Lower bound	Upper bound
SEIFA IER score, 2016								
All postcode areas	0.069	671	49.586	2.178	–684.930	4.72E–12**	1.571	2.785
Metropolitan areas	0.313	268	121.600	3.478	–2167.306	1.51E–23**	2.857	4.099
Regional areas	0.010	402	3.953	1.063	534.822	0.047*	0.012	2.114
SEIFA IRSAD score, 2016								
All postcode areas	0.007	671	4.558	–0.625	2174.181	0.033	–1.252	–0.052
Metropolitan areas	0.000	268	0.076	0.118	1270.037	0.783	–0.723	0.959
Regional areas	0.000	402	0.002	0.023	1578.924	0.964	–0.957	1.002
Change in SEIFA IER score, 2011–16								
All postcode areas	0.003	671	2.152	1.807	1512.906	1.43E–01**	–0.612	4.225
Metropolitan areas	0.023	268	6.224	4.888	1386.939	0.013*	1.030	8.745
Regional areas	0.000	402	0.131	–0.555	1603.124	0.718	–3.570	2.461
Change in SEIFA IRSAD score, 2011–16								
All postcode areas	0.011	671	7.466	2.613	1494.956	0.006*	0.735	4.491
Metropolitan areas	0.004	268	1.195	1.574	1387.099	0.275	–1.262	4.411
Regional areas	0.003	402	1.128	1.369	1584.425	0.289	–1.165	3.904
Rate of rented, occupied dwellings, 2016								
All postcode areas	0.195	688	166.485	–1679.980	1869.770	2.91E–34**	–1935.621	–1424.340
Metropolitan areas	0.485	274	256.862	–1971.650	1896.890	3.37E–41**	–2213.840	–1729.459
Regional areas	0.009	413	3.919	–560.201	1698.310	0.048*	–1116.500	–3.903
Rate of unoccupied dwellings, 2016								
All postcode areas	0.056	688	40.558	–907.548	1652.686	3.49E–10**	–1187.347	–627.750
Metropolitan areas	0.051	274	14.596	–972.691	1475.955	1.65E–04**	–1473.923	–471.459
Regional areas	0.164	413	80.954	–1549.247	1901.376	8.55E–18**	–1887.722	1210.771

Notes: VEECs were generated to 30 June 2017; SEIFA IER = Socio-Economic Indexes for Areas Index of Economic Resources; SEIFA IRSAD = Socio-Economic Indexes for Areas Index of Relative Socio-Economic Advantage and Disadvantage.
* Statistically significant at $p < 0.05$; ** = highly statistically significant at $p < 0.001$; p-values were not adjusted for multiple testing.

Table 7: Results of the linear regression model predicting the effect of the dependent variables on the Victorian Energy Efficiency Certificate (VEEC) generation intensity of lighting upgrades, differentiated by location.

Variable	r^2	ANOVA		Unstandardised coefficients			95% confidence interval for β	
		d.f.	F	β	Constant	p	Lower bound	Upper bound
SEIFA IER score, 2016								
All postcode areas	0.194	671	161.361	2.102	–1494.073	2.80E–30**	1.777	2.427
Metropolitan areas	0.239	268	83.794	2.218	–1506.667	1.47E–17**	1.741	2.695
Regional areas	0.076	402	32.808	1.182	–342.318	1.99E–08**	0.776	1.588
SEIFA IRSAD score, 2016								
All postcode areas	0.082	671	60.214	1.310	–687.597	3.18E–14**	0.979	1.642
Metropolitan areas	0.006	268	1.742	0.410	338.039	0.188	–0.202	1.022
Regional areas	0.060	402	25.708	0.978	–421.339	6.08E–07**	0.599	1.357

(Contd.)

Variable	r^2	ANOVA		Unstandardised coefficients			95% confidence interval for β	
		d.f.	F	β	Constant	p	Lower bound	Upper bound
Change in SEIFA IER score, 2011–16								
All postcode areas	0.000	671	0.126	–0.251	632.049	0.723	–1.644	1.141
Metropolitan areas	0.000	268	0.062	0.360	762.882	0.803	–2.488	3.208
Regional areas	0.001	402	0.294	0.332	542.204	0.588	–0.872	1.536
Change in SEIFA IRSAD score, 2011–16								
All postcode areas	0.014	671	9.774	–1.716	646.239	0.002*	–2.794	–0.638
Metropolitan areas	0.006	268	1.525	–1.297	767.538	0.218	–3.366	0.771
Regional areas	0.000	402	0.071	0.138	541.701	0.790	–0.876	1.151
Rate of rented, occupied dwellings, 2016								
All postcode areas	0.045	688	32.602	–462.093	725.297	1.68E–08**	–620.991	–303.195
Metropolitan areas	0.320	274	128.756	–1147.262	1054.905	1.05E–24**	–1346.310	–948.214
Regional areas	0.001	413	0.591	90.314	526.596	0.442	–140.590	321.218
Rate of unoccupied dwellings, 2016								
All postcode areas	0.089	688	67.062	–653.582	730.855	1.28E–15**	–810.284	–496.880
Metropolitan areas	0.021	274	5.899	–449.373	797.364	0.016*	–813.629	–85.118
Regional areas	0.073	413	32.512	–426.580	627.252	2.26E–08**	–573.644	–279.516

Notes: VEECs were generated until 30 June 2017 from lighting upgrade activities.
SEIFA IER = Socio-Economic Indexes for Areas Index of Economic Resources; SEIFA IRSAD = Socio-Economic Indexes for Areas Index of Relative Socio-Economic Advantage and Disadvantage.
* Statistically significant at $p < 0.05$; ** highly statistically significant at $p < 0.001$. *p*-values were adjusted for multiple testing.

Table 8: Results of the linear regression model predicting the effect of the dependent variables on the Victorian Energy Efficiency Certificate (VEEC) generation intensity of water heating upgrades, differentiated by location.

Variable	r^2	ANOVA		Unstandardised coefficients			95% confidence interval for β	
		d.f.	F	β	Constant	p	Lower bound	Upper bound
SEIFA IER score, 2016								
All postcode areas	0.001	671	0.406	0.122	192.870	0.524	–0.254	0.499
Metropolitan areas	0.214	268	72.863	0.768	–694.417	1.06E–15**	0.591	945.000
Regional areas	0.011	402	4.275	0.603	–138.440	0.039*	0.030	1.177
SEIFA IRSAD score, 2016								
All postcode areas	0.051	671	36.270	–1.076	1399.510	2.83E–09**	–1.427	–0.725
Metropolitan areas	0.059	268	16.676	0.451	–376.590	5.90E–05**	0.234	0.669
Regional areas	0.000	402	0.004	0.017	449.903	0.950	–0.518	0.552
Change in SEIFA IER score, 2011–16								
All postcode areas	0.008	671	5.473	1.720	312.056	0.020*	0.276	3.163
Metropolitan areas	0.089	268	26.178	2.581	88.596	5.96E–07**	1.588	3.574
Regional areas	0.000	402	0.064	–0.211	467.440	0.801	–1.857	1.435
Change in SEIFA IRSAD score, 2011–16								
All postcode areas	0.059	671	42.070	3.620	285.181	1.71E–10**	2.524	4.716
Metropolitan areas	0.074	268	21.280	1.709	85.795	6.00E–06**	0.980	2.439
Regional areas	0.009	402	3.510	1.315	450.626	0.062	–0.065	2.694

(Contd.)

Variable	r^2	ANOVA		Unstandardised coefficients			95% confidence interval for β	
		d.f.	F	β	Constant	p	Lower bound	Upper bound
Rate of rented, occupied dwellings, 2016								
All postcode areas	0.187	688	157.863	−952.780	520.782	9.73E−33**	−1101.671	−803.890
Metropolitan areas	0.271	274	101.705	−370.185	188.194	1.55E−20**	−442.450	−297.921
Regional areas	0.106	413	48.852	−1013.554	649.577	1.11E−11**	−1298.611	−728.497
Rate of unoccupied dwellings, 2016								
All postcode areas	0.021	688	14.561	320.566	262.619	1.48E−04**	155.621	485.512
Metropolitan areas	0.032	274	9.091	194.487	68.392	3.00E−03*	67.498	321.476
Regional areas	0.034	413	14.283	−376.713	538.175	1.80E−04**	−572.651	−180.774

Notes: VEECs were generated until 30 June 2017 from water heating upgrade activities.
SEIFA IER = Socio-Economic Indexes for Areas Index of Economic Resources; SEIFA IRSAD = Socio-Economic Indexes for Areas Index of Relative Socio-Economic Advantage and Disadvantage.
*Statistically significant at $p < 0.05$; **highly statistically significant at $p < 0.001$. p-values were not adjusted for multiple testing.

Table 9: Summary of multiple regression analysis for Victorian Energy Efficiency Certificate (VEEC) generation intensity across all postcode areas.

Variable	B	SEB	β	t	p
Intercept	1874.915	32.647		57.429	2.95E−264
Rate of rented, occupied dwellings, 2016	−0.09	0.03	−0.11	−3.029	0.003*
Rate of unoccupied dwellings, 2016	−1536.34	137.848	−0.404	−11.145	1.25E−26**

Notes: B = unstandardised regression coefficient; SEB = standard error of the coefficient; β = standardised coefficient.
* Statistically significant at $p < 0.05$; ** highly statistically significant at $p < 0.001$.

Table 10: Summary of multiple regression analysis for Victorian Energy Efficiency Certificate (VEEC) generation intensity across metropolitan postcode areas.

Variable	B	SEB	β	t	p
Intercept	1912.695	39.57		48.337	1.51E−135
Rate of rented, occupied dwellings, 2016	−0.051	0.031	−0.073	−1.619	0.107
Rate of unoccupied dwellings, 2016	−1916.41	127.311	−0.677	−15.053	1.15E−37**

Notes: B = unstandardised regression coefficient; SEB = standard error of the coefficient; β = standardised coefficient.
** Highly statistically significant at $p < 0.001$.

4.4. Sensitivity analysis of VEECs generation intensity per household

A sensitivity analysis was conducted to explore the VEECs generation intensity by households rather than dwellings. In contrast to other work that equated dwellings with households (Best *et al.* 2019), this study worked on the premise that only occupied dwellings contained households, namely one household per occupied dwelling. More than 11% of dwellings in Victoria were unoccupied in the Census 2016 (ABS 2019a). The VEECs generation intensity was recalculated as the number of VEECs generated for every 100 occupied private dwellings (Equation 2):

$$\text{VEECs generation intensity} = \frac{\text{Total number of VEECs generated}}{\text{Number of all occupied private dwellings in Census 2016}} * 100$$

When mapping, one outlier (POA 3944) was removed to provide meaningful gradation in colour. The spatial mapping of the VEECs generation intensity per household showed scattered areas of high intensity across Victoria. Small area clusters with similarly high VEECs generation intensities were apparent at the tip of the Mornington Peninsula (**Figure 7**), along the Murray River, in Lake Eildon, along the Surf Coast and Bass Strait, and north of Lakes Entrance (**Figure 8**). These hotspots accommodate weekend and summer retreats of Melbournian families. Many of these were empty on Census night, a Tuesday evening in the middle of winter, *e.g.* Lake Eildon (48.5% unoccupied dwellings).

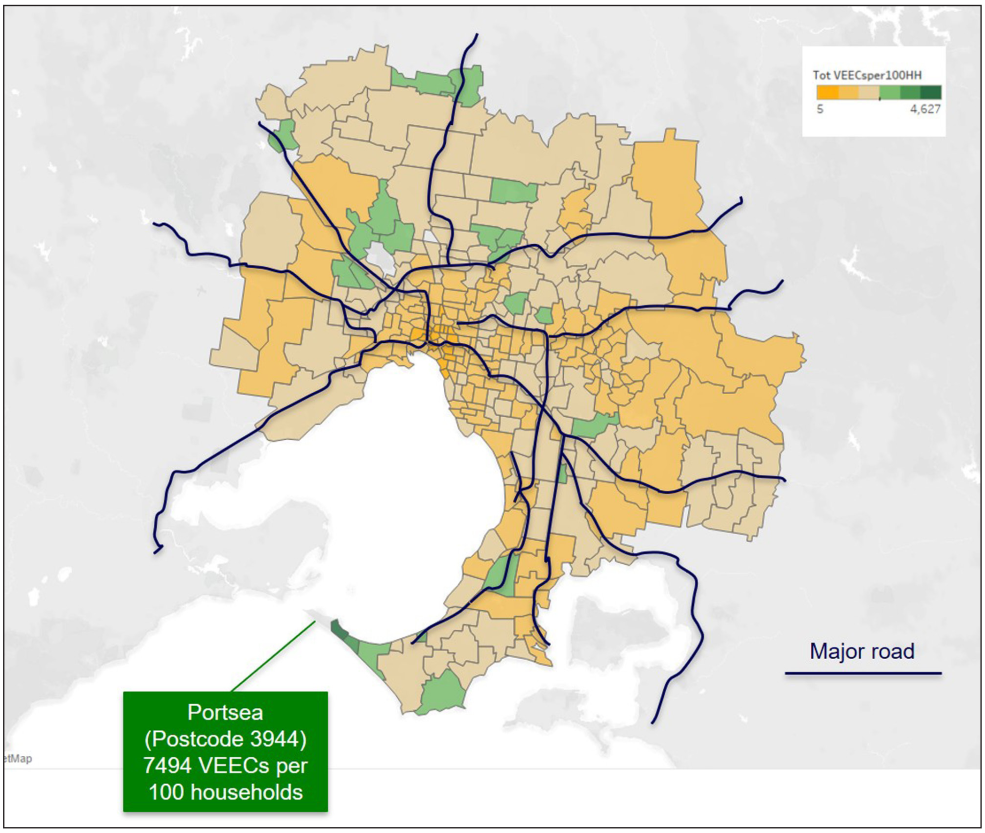

Figure 7: Spatial mapping of Victorian Energy Efficiency Certificate (VEEC) generation intensity per household, excluding postcode area 3944.

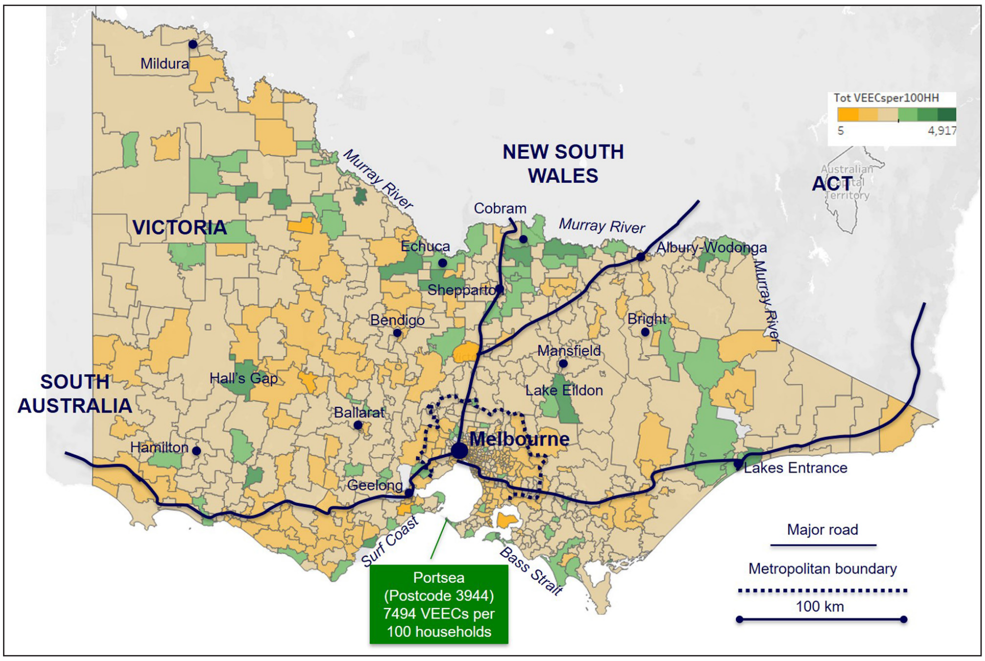

Figure 8: Spatial mapping of Victorian Energy Efficiency Certificate (VEEC) generation intensity per household, excluding postcode area 3944.

4.5. Outlier case study

The extreme outlier of Portsea (Postcode 3944) at the tip of the Mornington Peninsula was investigated further to try to explain the unusually high VEECs generation intensity (**Figure 9**). The distribution of certificates across activities was not unusual. The postcode area's SEIFA indices in the top two deciles indicated that the residents were wealthy and well-educated. The rate of rented dwellings was low, the rate of empty dwellings unusually high. Portsea is promoted as the holiday location of Melbourne's 'rich and famous' (Visit Melbourne 2019).

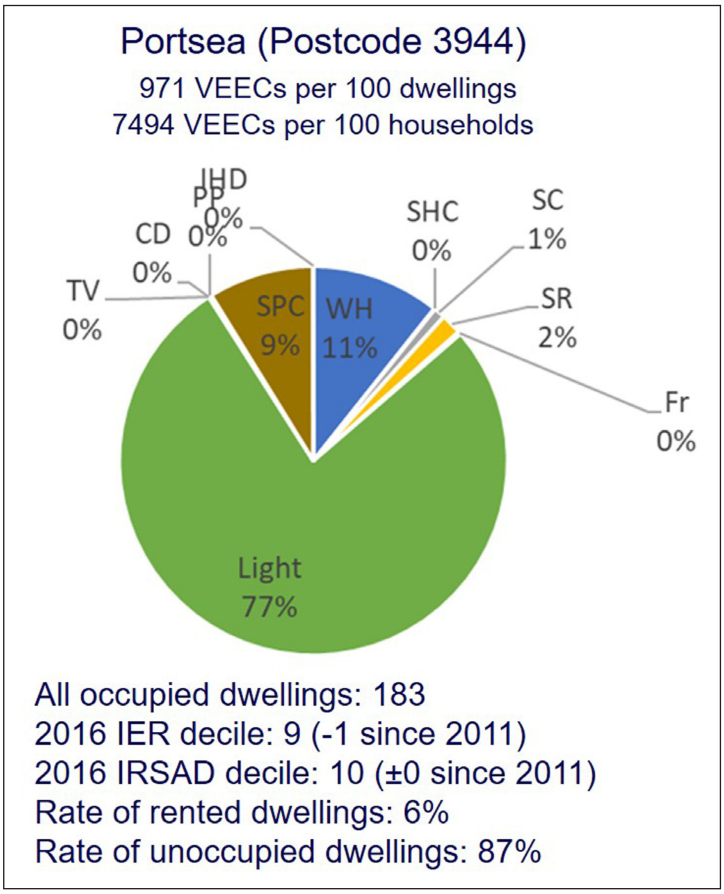

Figure 9: Summary of the Victorian Energy Efficiency Certificate (VEEC) generation and key socioeconomic indicators for the top outlier metropolitan postcode area 3944 (Portsea).

5. Discussion

This study used a spatial approach to test the relationships among the generation of white certificates, socioeconomic and tenure characteristics, and location. Relatively high VEECs intensity was found in regional areas. This suggests that dwellings in regional areas may have contributed relatively more to reducing the state's residential carbon emissions than metropolitan ones. The nature of the VEEC activities in regional dwellings may have further reduced household energy costs because of the relatively high uptake of upgrades with a fuel switch. Alongside this, initial capital investments would have been higher in regional than in metropolitan dwellings.

Considering that the VEU programme is a market-based mechanism, this finding was surprising as it contradicts the economics of agglomeration and the European experience of a relative disadvantage in residential retrofit subsidy benefits in peripheral areas (Lihtmaa *et al.* 2018; Turcu 2016). One explanation was the relatively high share of VEECs generated by water heater upgrades. Regional areas have a greater prevalence of electric water heaters than those in metropolitan Melbourne, where reticulated gas is common and often used for domestic hot water provision. The finding may also reflect more intensive engagement with subsidies in regional than metropolitan areas. This pattern parallels the uptake of solar PV installations in Victoria, which has been found to be significantly higher in rural areas than in urban or suburban postcodes (Chandrashekeran & Li 2019).

Analysis of the data strongly suggests that inequities in the accessibility of retrofit subsidies have reinforced distributional inequalities. The relatively low levels of subsidy benefits in areas with low economic resources and high percentages of rented properties suggests that non-targeted financial incentives may be regressive and (re)produce energy inequalities. Considering that wealthier households account for higher carbon emissions than lower income families (Wiedmann *et al.* 2008), high VEECs generation intensities in more advantaged areas may be perceived as effective from a purely decarbonisation effectiveness perspective. However, as the most common activities were offered free of charge and as low-income and rental households are at a higher risk of energy stress, this study suggests that financially deprived and renting population groups may have experienced a double disadvantage, *i.e.* of energy and retrofit inequality. The burden on low-income households may have been reduced by energy concessions that are calculated as a percentage of the bill amount (DHHS 2018). However, eligibility criteria do not address the energy efficiency of the dwellings or tenure. Regressive retrofit grant distributions have also been observed in Estonia and Bucharest (Romania) (Lihtmaa *et al.* 2018).

5.1. Low-carbon gentrification

The observed link between water heating upgrades and increases in affluence and advantage in the metropolitan areas endorsed the concept of 'low-carbon gentrification', *i.e.* the interaction of housing improvements and upward social change (Bouzarovski, Frankowski, & Tirado Herrero 2018). More research is needed to explore to what extent and in which ways this phenomenon may have led to the displacement of low-income tenants or other potentially disadvantaged groups.

The regressive outcome of subsidies to improve domestic energy demand among low-income households and renters seems to be compounded by a lack of access to decarbonise and reduce the costs of their energy supply. Recent work investigating the spatial coverage of the SRES found that, across Australia, renters were less likely to benefit from solar microgeneration subsidies (Best *et al.* 2019). This highlights that non-targeted low-carbon incentives are likely to (re)produce social inequalities. In contrast to the present study, which showed a linear association of VEECs generation intensities and economic wealth of areas, the solar PV subsidy uptake was particularly high in postcode areas with middle-income households (Best *et al.* 2019). Hence, it appears that varied mechanisms shape the uptake of the different types of low-carbon material home improvements.

The spatial concentrations of high VEECs generation intensities both within and outside the metropolitan boundary of Melbourne echo the neighbourhood effect that has been observed in solar PV installations in Victoria (Chandrashekeran & Li 2019) and solar PV subsidy penetration across Australia (Burke, Best, & Nishitateno 2019). The spatial concentration of hotspots may be due to the geographical coverage of retrofit provider services (Gooding & Gul 2017), to a snowballing effect of successful retrofit initiatives (Lihtmaa *et al.* 2018) or shared prevailing contextual conditions. One possible reason may be the sea and tree change phenomenon, the migration of affluent householders retiring to the Mornington Peninsula, Bass Strait, country Victoria and small towns along the Murray River (Luck *et al.* 2010). The hypothesis that affluent baby boomers may play a key role in the upscaling of the energy refurbishment of homes is supported by evidence that self-funded retirees have been more likely to install solar PV panels than lower income state pension recipients (Best *et al.* 2019). This also means that both white and green certificate schemes in Australia may inadvertently promote free-rider problems.

Another possible explanation may be the social normalisation of residential retrofit activities that extends beyond the main place of residence to the second home. Numerous of the holiday areas on the Mornington Peninsula with high VEECs generation intensities per household and low occupation rates have also presented high penetrations of solar PV panels (Chandrashekeran & Li 2019). This suggests that energy improvements of homes may have become a routinised feature in home maintenance, at least among the more affluent households. Beyond concerns about equity, the use of VEU grants for second homes raises questions about the effectiveness of the scheme. If intermittently occupied homes received subsidised activities, then the expected carbon emissions reductions may not have been achieved.

The value of spatial research on inequities in access to retrofit opportunities lies in its usefulness in monitoring and comparing outcomes over time and across areas. This study showed that retrofit poverty is a multidimensional issue with monetary, social and structural indicators which may require a multifactorial index. Maps may visualise variations in retrofit poverty or the outcomes of initiatives that aim to promote energy-efficiency improvements, assist in identifying areas that seem to be missing out and facilitate targeted interventions. However, the marketing of retrofit programmes in specific geographical areas may need sensitive communication as they may be interpreted as stigmatising if they imply high levels of energy hardship (Reid, McKee, & Crawford 2015).

5.2. Limitations

A key variable in understanding the geography of access to retrofit subsidies is the unit of analysis. This study aggregated data to the postcode level. This method limited conclusions referring directly to conditions that may have explained the divergence of outcomes. In addition, the association between the various independent variables and VEECs generation intensity does not signify a causal relationship. The spatial and sociodemographic differences in access to retrofit activities may, however, advance research into the phenomenon of retrofit poverty as more than a financial disparity.

Future research may consider sampling at dwelling unit level and approach energy-efficiency improvements as the dynamic sociotechnical system characterised by the interactions among people, place, properties and providers. Drawing on a public health framework (Duncan, Jones, & Moon 1998), it is recommended that future investigations aim for a deeper understanding of the relationship between contexts (including geographical and climatic region, time, regulations, localised programmes/innovations), compositions (such as diversity of people, dwellings and retrofit services) and conditions (which may be systemic, social, individual or pertain to the capabilities and practices around private and professional retrofits).

6. Conclusions

This study highlights that policies and subsidy programmes seeking to lower energy costs and carbon emissions may inadvertently exacerbate social and economic inequalities. Residential energy-efficiency retrofit subsidy disparities in Victoria appeared to be patterned along the axes of economic inequality and tenure. Thus, the programme may have compounded the burden of energy hardship among low-income households and renters. In the context of the Paris

Agreement and the capabilities approach, policy tools are required that follow principles of restorative justice and a distributional approach to low-carbon energy access. Under such tools, people with the largest needs would be assisted first and to the largest extent.

In the case of the state of Victoria, retrofit poverty is spatially distributed through tenure as well as through income. In this case, therefore, a policy response to address retrofit poverty would include these variables in design and would be more overtly tailored to address the needs arising from existing inequalities. For the VEU programme, for example, this may take the form of targeting support by locale, income and/or tenure so as to perform a restorative justice function. This would ensure that households with limited financial resources participate and benefit from the programme more in accordance with need. The perspective of the capability approach, which also considers structural constraints, such as tenancy laws and the relative constraints they impose upon retrofit capability, points towards the need for specific policy attention to rental tenures. For example, from a distributive justice perspective, there is a greater policy need for minimum energy-efficiency standards for rental housing than for other tenures. Free VEU activities, such as efficient lighting and low-flow shower roses, may be sanctioned by landlords and would be effective in countering inequality if they were mandated for rental properties.

This paper demonstrated how retrofit poverty is a multidimensional issue with monetary, social and structural indicators. In testing and advancing the term, energy poverty was differentiated as a consumption inequality indicator, from retrofit poverty as the inequality of opportunity to improve the energy performance of the home. This perspective allows the evaluation of low-carbon transition policies in terms of social impacts and the need to consider retrofit participation disadvantage. A restorative justice approach points to tailored retrofit-enabling schemes targeted at enhancing capabilities of groups with limited resources and agency.

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Competing Interests
The authors have no competing interests to declare.

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