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Econometric modelling of determinants of COVID-19 impact in the Australian residential solar market

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Certificate of Original Authorship

I, Rao Natasha Ali declare that this thesis is submitted in fulfilment of the requirement for the award of Master, in the School of Mechanical and Mechatronic Engineering/ Faculty of Engineering & IT at the University of Technology Sydney.

This thesis is wholly my own unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not submitted for qualifications at any other academic institution.

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Table of Contents

List of Tables

Table of Figures

Abstract

The COVID-19 pandemic, which appeared as an unexpected global crisis, has severely influenced almost every aspect of human life including socioeconomic and demographic activities. As countries faced the continual proliferation of the virus and resulting lockdowns, various industries encountered substantial complications, including the renewable energy sector. Given the complexity of the pandemic, it is crucial that governments and politicians evaluate the COVID-19 pandemic effects on communities and economies in order to plan for recovery and future pandemics. While the health sectors have acquired the uppermost priorities during this pandemic, other challenges, such as higher electricity demand and reducing carbon emission goals, cannot be overlooked as the drastic effects of global warming still prevail, which may result in continual and detrimental bushfires in Australia. Therefore, the importance of enlarging Australia's clean energy sources has become even more pronounced. In the context of solar energy market in Australia, residential solar comprises one-fourth of Australia's total renewable energy resource and is indispensable to the economy. However, the effect of COVID-19 on the residential solar market has yet to be explored.

This research aims to analyse the effect of COVID-19 lockdown on residential solar PV adoption in Australia, while considering the influence of other important socioeconomic and demographic factors using the cross-section regression method.

To underpin lockdown's impact comprehensively, two main model types are employed. The first model called the contemporaneous model is used to determine the immediate effect of lockdowns. This model indicates the varied impact of active lockdown duration on residential solar adoption across the states suggesting curtailment in Victoria. In contrast, there is a rising trend in the postcodes for New South Wales and the Australian Capital Territory. Conversely, Queensland, Northern Territory, South Australia, and Tasmania showed no significantly conclusive results. The second model called a lag model is employed to study the medium-term lockdown impacts which showed a significantly sustained but variable association of solar adoption with lag lockdown duration.

The inclusion of socioeconomic and demographic factors is performed considering the factors that might be linked to COVID-19-driven higher electricity consumption thus affecting the decision to adopt solar during this period, for example, the number of children and different variables for house ownership with and without a mortgage. These variables are not studied previously in similar studies. The study implied that separate houses, older age, larger household size, greater number of bedrooms, level of education, and higher proportion of females in a postcode were motivating the solar uptake during the pandemic. Further analysis suggests that the married individuals and families

with more children were less likely to install solar during this period. Furthermore, to analyse the full-scale impact of COVID-19 lockdowns on the solar energy uptake, individual interaction models for active and lagged lockdown duration are integrated into the study to estimate the influence of socioeconomic and demographic characteristics associated with lockdown duration effect on residential solar diffusion in Australia during the pandemic. The findings showed a rise in uptake was suggestively associated with separate houses, dwellings with a larger number of bedrooms, a greater number of persons in a household, married individuals, and homes that are owned with mortgages were more likely to install solar in postcodes with longer active lockdowns. In contrast, individuals with a university level of education living in longer active lockdown postcodes were less likely to install solar during the pandemic. However, the lag interaction model has signified a more persistent yet similar association except for houses owned outright, which showed no evidence of correlation and Small-scale Renewable Energy Scheme (SRES) zone rating, with a strong suggestive correlation for solar adoption in postcodes with longer past lockdowns.

The uptake might be enhanced through climate change and sustainability-aimed educational programmes for university-educated people, while financial incentives like subsidised loans, competitive Feed-in-Tariff, tax credits, and tax deduction policies may encourage solar adoption among people with larger households and spacious residences. The study reassesses the factors affecting the residential solar uptake in the wake of the catastrophic event of COVID-19, changing individuals' lifestyles and hence might have altered the determinants of solar adoption decision-making. This study's findings can assist in formulating the post-pandemic residential solar energy regulations by identifying the relationships between variables in the pandemic context.

Chapter 1 - Introduction

1.1 Background

Global warming has ended up being the focus of the world ecological problems, specifically in the last few years. This escalating global climate crisis, is now a nearly unanimous agreement among scientists that the Earth's average temperature and ocean levels are increasing as a result anthropogenic greenhouse gas emission, with carbon dioxide (CO_2) being the primary source(1, 2). Significant implications result from this concerning pattern, such as instabilities in agriculture productivity, creating threats to food sustainability and the escalation of global warming, more regular instances of drought, and geopolitical conflicts arising from water resource crises (3). These discoveries emphasise the pressing necessity for a substantial transformation in energy generation and consumption methods. Fossil fuels, being a predominant energy source, significantly contribute to the carbon dioxide (CO_2) emissions associated with energy, accounting for almost 60 per cent of the total greenhouse gases (GHG) (4), (5). Hence, a global shift in energy from fossil fuels to renewable sources has become fundamentally imperative. Among the methods to manage global warming that creates environmental adjustment is embracing the renewable resource power strategy. Various clean energy resources: solar, geothermal, wind, bioenergy, hydro, and aquatic are presently the foundation of lasting and eco-friendly energy alternates. The successful commissioning of these renewable resources depends on several factors such as geographical placements, weather conditions, technological restrictions, and governmental and public support. Although these several renewable energy resources may fulfil current energy needs, the challenges of increasing demand for electricity, air pollution and global warming are also increasing (6). Therefore, the world inhabitants need to resource renewable energy sources to reduce the carbon emissions whose targets were presented at the Paris climate agreement (7). Although Australia is recognised as a chief contender to assist upsurging renewable energy resources to decrease dependence on fossil-fuel based power stations (8), it still has large amounts of greenhouse gas (GHS) emissions per capita in the environment (9), thus emphasising the need for cost-effective and nationwide acceptable renewable energy source such as solar energy.

1.1.1 Rising demands of electricity generation

The usage of electricity is an essential part of our daily life as billions of items worldwide work on electricity. Traditionally, it has been generated using fossil fuel such as coal-based generation systems. The world has also been working to alternate resources with minimal carbon emissions to achieve an eco-friendly environment. As revealed in a recent prestigious study on electricity requirement forecast, a fleet of 350 million electric vehicles will be produced by 2050, increasing annual electricity demand to 41% of recent levels (10). It is also concluded that only converting fuel type for millions of vehicles to electric is not enough to meet the climate change targets. There is a severe need for reprioritising the actions and effective parameters for electricity generation and consumption [1]. Therefore, there is a strong need of studying all the technological, social, and environmental factors to make a strategic framework and roadmap for clean energy resources such as solar energy.

1.2 Energy as a global issue

Energy is generally defined as a fundamental physical quantity that is paired with the ability to perform and/or drive a work or cause a change in the physical system. It considered as an elementary force that impels most of the activities in our contemporary society. From supplying power to businesses, industries, and residences to fuelling our modern scientific, agricultural, medical and transportation systems, energy plays a crucial role in fostering human advancement in every field of the modern lifestyle. While there are numerous ways of employing different forms of energy for our practical use, the detailed study of acquiring, converting, and utilizing energy for practical purposes requires knowledge from a wide range of fields, including physics and engineering, as well as economics, geography, and social sciences.

Energy can manifest in diverse forms and can be categorised into distinct classifications based on the characteristics of its expression. Thermal energy is a form of energy that is associated with the temperature and heat of a system. Chemical energy is a type of energy that is stored in the chemical bonds of molecules. Mechanical energy is a form of energy that is associated with the position or motion of objects. Electrical energy is a type of energy that is carried by electric charges. Nuclear energy is a form of energy that is released during nuclear reactions. As per the principle of the conservation of energy, energy cannot be created or destroyed yet can be converted from one form to another form of energy. Altogether, energy can be interconverted and sourced from either form of thermal, nuclear, chemical, mechanical, or electrical processes.

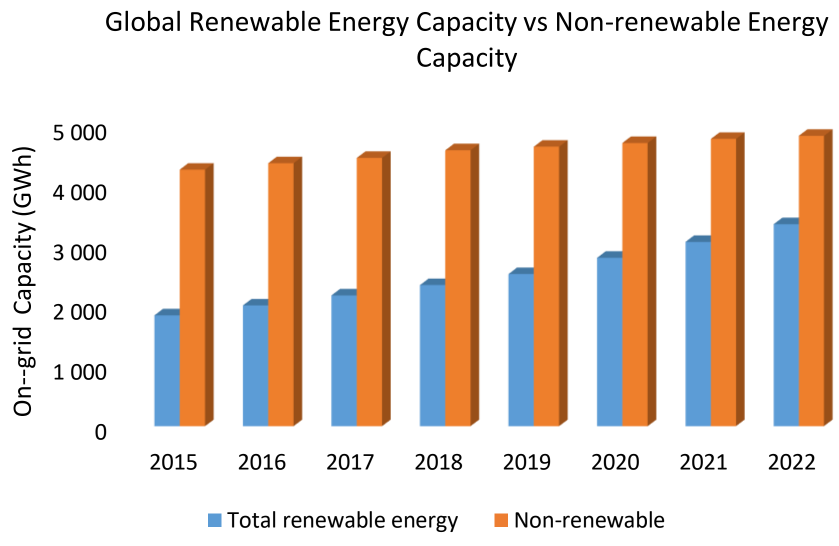

Figure 1.World's total renewable energy installed capacity vs on-grid non-renewable energy installed capacity (11).

While there are numerous sources of energy generation and conversion methodologies developed especially is recent few centuries, these energy sources can be broadly classified as renewable and non-renewable energy sources. Generally, energy acquired from utilising fossil fuels (coal, oil, and natural gas) and nuclear fuels is classified as non-renewable energy sources while renewable energy sources are those that are naturally regenerated and are almost impossible to deplete completely. Majorly, renewable energy sources offer a sustainable and environmentally friendly alternative to conventional fossil fuels-based energy sources which has proven to cast detrimental effects on our planet. Lately, there has been a significant upsurge in renewable energy sources development needs due to mounting climate change, vulnerabilities in energy supply, and the desire for a more sustainable future. Therefore, renewable energy sources are regarded as sustainable and abundant sources that not only have the potential to satisfy a sizeable amount of the world's energy requirements, but also represent a significant step towards a green and secure future for our planet.

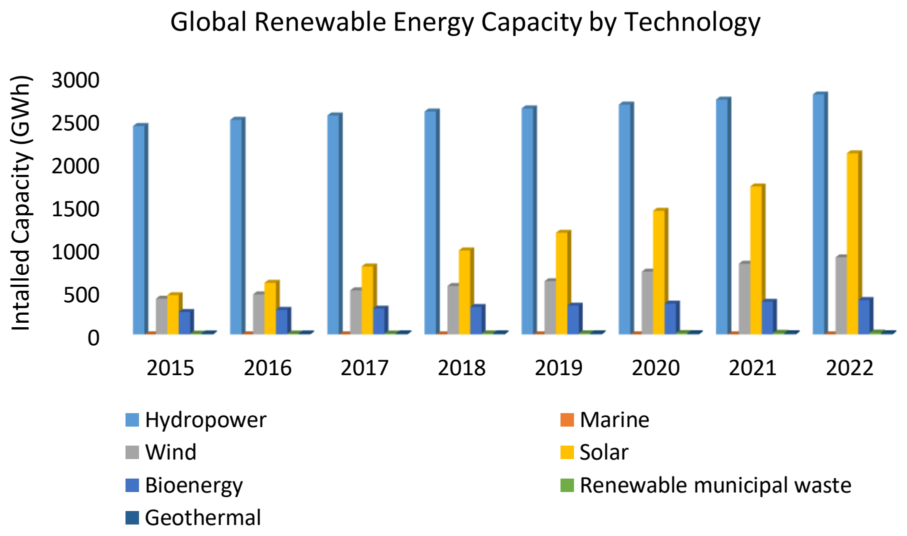

Figure 2. Global renewable energy capacity by technology (11).

There are various types of renewable energy sources that exhibit unique characteristics and practical applications, primarily determined by the natural abundance of these sources. Renewable energy sources such as wind power, hydropower, biomass, and geothermal energy are widely acknowledged. Another form of converting energy is called solar energy which is the process of converting sunlight into usable electricity or thermal energy. The harnessing of solar energy can be accomplished through diverse technological means, including photovoltaic (PV) systems, concentrated solar power (CSP) plants, and solar water heating systems. Due to its decentralized and abundance throughout the globe, solar energy generation and employing possesses significant implications across various aspect of our modern life ranging from environmental and economic to social and demographic aspects.

1.3 Why generating solar energy is important

Solar power has become a significant element of Australia's sustainable energy domain, vital in meeting the country's energy demands and environmental objectives. The ingrained adaptability and accessibility of solar power make it an intriguing choice, especially in residential settings. Solar energy can be effectively utilised on a small scale by installing residential solar without the need for complex infrastructure or geographic limitations (12). Ensuring accessibility is crucial since it guarantees that a broader range of inhabitants can actively engage in the shift towards renewable energy alternatives. Not all households can install wind turbines on their premises, making solar energy a more accessible and practical option for homeowners and companies (13). Small-scale solar generation improves individual energy self-sufficiency and significantly contributes to reducing greenhouse gas emissions on a larger scale (4). The versatility and scalability of solar power, primarily through rooftop installations, highlight its crucial role in Australia's renewable energy transition (14) (15)and the achievement of research goals focused on renewable energy diffusion.

1.4 Solar energy for electricity generation

In the cluster of many renewable energy technologies, solar energy is regarded as the most rapidly expanding clean energy sector globally (16). This type of energy generates the opportunity for the industrial practice of innovative technologies, resources and development structures of the solar energy market. Although the cost of solar system installation has dropped over the last decade, it still possesses a higher initial installation to electricity generation cost ratio than for conventional energy technologies. From the governmental perspective, solar energy markets benefit from the economic and governing enticements and mandates, feed-in tariff (FiTs) (17), tax breaks (18), renewable electricity standards (RES), privileged interest rates (19), and voluntary programs for green power procurement in numerous countries (20). Feed-in Tariffs (FiTs) were first introduced at higher rates to encourage the rapid adoption of renewable energy sources, specifically residential solar. Incentive programmes like these were introduced as a response to the growing concerns over climate change and the pressing necessity to mitigate greenhouse gas emissions (21, 22). They were first introduced in the 1990s in different European countries and in Australia starting from 2008 (23). Studies showed that states with financial incentives like grants and rebates observed greater and faster adoption of solar PV technology than states without them (24, 25). Meanwhile, continuous progress in solar technology resulted in decreased costs of photovoltaic (PV) systems, making them more feasible to a broader demographic of consumers. Nevertheless, the escalating number of installations and the mounting financial strain on governments and utilities prompted governments worldwide to curtail the incentives to uphold the long-term viability of the programmes and ensure equitable allocation of costs among energy customers (26, 27) (28). In addition, with the development of solar energy technology, there has been a continues decline in the prices for solar system, making it more

affordable to adopt (29), (30). Regardless of the immense development and technological potential, the worldwide market-led disposition of solar power technologies has countless technical and monetary obstructions.

1.5 Solar cell technology

There are several and diverse approaches to harnessing energy from cosmological radiation. Sunlight is enormous, innocuous, and clean energy to incorporate into the world clean energy resources list. Converting the sunlight into electricity is one of the most valuable and productive ways to harness it as an energy source. Solar power technology encompasses three types solar photovoltaic (PV) cells, concentrating solar power (CSP) and solar heating & cooling system (SHC). Photovoltaics generates electricity directly from sunlight, whereas CSP systems employ thermal energy from solar radiations to drive turbines for electricity generation. Lastly, SHC is used for residential, commercial, and industrial space heating and water heating. Solar cooling systems have two types: absorption chiller systems and desiccant systems former uses a collector, and an absorber for air-conditioning collectors are solar water heaters. The latter one passes over cooled air using silica gel as desiccant solar heat is used to dry the desiccant. Solar heating systems also are of two types, passive solar heating systems and active solar heating systems. An active solar system is typically used for space and water heating applications like solar hot water systems. Whereas this process of utilising solar energy can decrease electrical consumption for heating systems, systems of these kinds are usually impractical for large scales. They have characteristic effectiveness and cost challenges (31). However, CSP technologies employ mirrors to collect and transform sunlight into heat, which is used to spin a steam turbine that produces electricity (32). Therefore, PV technology has an advantage over CSP systems for residential and commercial applications with the lesser initial installation cost.

The photovoltaic (PV) solar cell was initially developed at Bell Telephone Laboratories in 1954. The word “photovoltaics” is descended from the procedure that converts the incident energy that is photons of light into the flow of electric current or voltage and is attributed as the “PV effect”. The device is called the PV cell. Primarily, most PV cells possess a similar working principle of transforming photons of light to the flow of electric charge that governs electric potential. In PV cells, semiconductor material film absorbs the incident photons of light or solar radiations, causing a flow of electrons and positively charged cavities known as holes. In a closed-circuit configuration, electrons start flowing, resulting in electric potential before reuniting with the holes on the positively charged side of the cell. This flow of current is generally called a photocurrent. In simple terms, this charge flow is considered an electricity generation phenomenon that can supply electric power to numerous domestic and industrial devices or equipment by converting solar panel generated direct current into alternating current using equipment called an inverter (33).

1.6 Solar energy at the global scale

In principle, the earth receives enough solar radiation that could be harnessed to generate enough electricity to supply global demand if technological barriers can be fulfilled. In the twentieth century, the global PV installed capacity has dramatically increased from less than 10 GW to nearly 1500 GW with an exponential rise due to various technological, policy, business and market developments. The data of a globally installed system to generate solar energy is shown in Figure 3, published by the International Renewable Energy Agency (IRENA) (34). The data illustrates that solar power installed capacity has significantly soared in the last decade. This data demonstrates that China dominates the solar energy market as it amplified its generation capacity by nearly 60 gigawatts in the single year of 2017 (35), which represented 58 % of the world's total PV installed capacity, followed by Europe (25 %), America (15 %), the Middle East and Africa (2%). The continual trend of solar system installation kept increasing till 2020, when the global solar system installation capacity soared by nearly 700% in the last decade. As of 2020, Asia dominates the overall solar installed capacity comprising ~57%, followed by Europe (23%), North America (12%), Australia and South America (2%) and other regions with less than 1% contribution to the global solar energy installed capacity. Although Asian countries contribute more to the global installed capacity, when comparing the Asian population with the European population, Europe dominates the solar energy utilisation per capita.

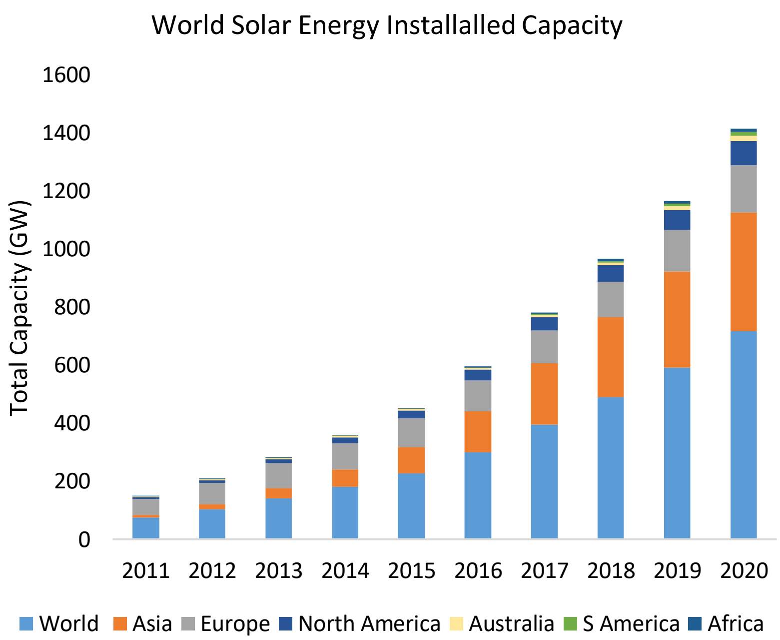

Figure 3. Global solar energy system installed capacity in the last decade. An exponential rise in the trend is visible, with Asian countries taking the lead in installation, followed by Europe, North America, Australia, and Central America. Data has been taken data taken from reference (34).

As the global solar system installation capacity depends upon numerous ecological, geographical, socio-economic factors, Australia possesses a top position of utilising solar energy amount relative to other renewable energy sources. As per data from IRENA (34), Australia generates nearly 50% of its renewable energy from solar energy sources, emphasising the larger solar energy business market in Australia. Solar system installation in Australia had continued to increase in the last decade, with peak installation until the start of 2020 before the COVID-19 pandemic affected the overall economy.

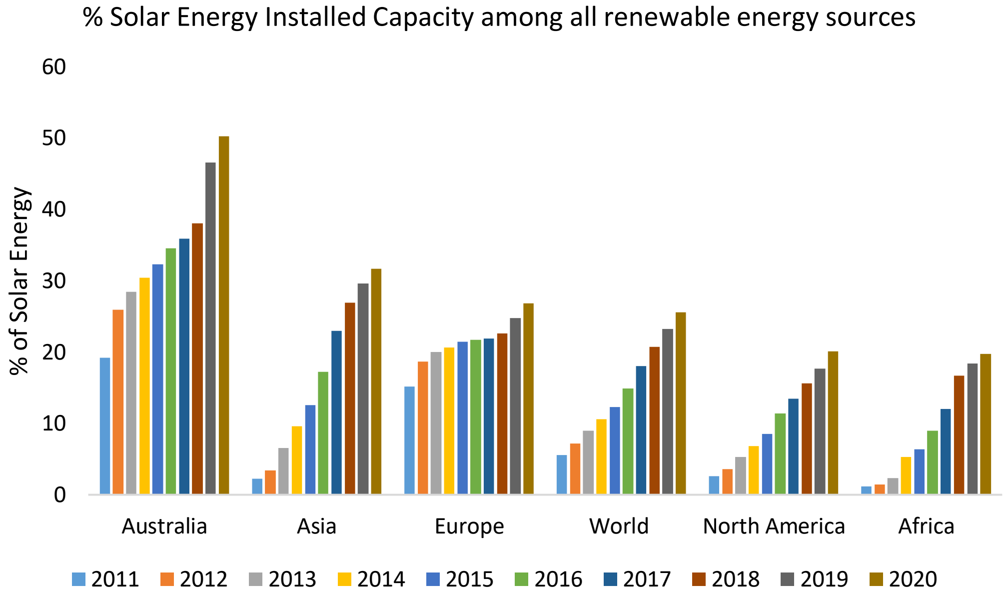

Figure 4. %age of solar energy installation capacity among all available renewable resources. The data shows an overall trend of utilising solar energy as means of renewable energy Australia has a higher % than the regions shown. Data has been taken from reference (34).

Currently, the total PV solar power generation capacity of the US is approximately 60 gigawatts. At the start of the last decade, the American government took many encouraging steps in the solar energy market by spending heavy expenditures on its development, especially in the previous decade. The US government adopted the policy to reinforce green electricity generation containing a combination of economic rebates and authorised merits to sustain the solar power competitiveness among other renewable energy resources. In the last decade, regardless of solar energy's fast technological and business expansion within the United States, a trivial volume of energy utilisation has been assigned to solar power. In this regard, the higher installation and production cost of PV panels is considered the primary reason behind this small volume and conversion of solar power utilisation in the USA. Although the levelized cost of electricity (LCOE) produced from solar energy has been reduced significantly in the last decade can still be higher than for other sources. Another main obstacle in the past was the lack of political interest to legislate reductions in carbon emissions utilising renewable energy. A significant example of this leaving from the Paris climate agreement might have a detrimental effect on our climate and the solar energy market in the present decade (36).

European nations have made significant progress in the advancement of solar energy. The outcomes are of significant interest to stakeholders, policymakers, and commercial businesses in enlarging photovoltaic power stations. In addition, to acquire cost-effective equipment for solar systems, European countries have also laid a particular focus to provide publicly and quickly accessible technical assistance in evaluating a suitable positioning site for solar panels based on the solar irradiance measurement (37). It is a great initiative to help the local market and even individual householders. Solar power accounts for approximately 4% of the total demand for electricity in Europe on average, and in the most developed solar markets like Germany, this figure reaches approximately 8%. Significant growth was observed in the European solar market in the year 2015. There was a 15% increase in demand relative to the preceding year. In Europe, solar energy demand is primarily driven by the United Kingdom, Germany, and France. The solar markets of these countries fulfil 75% of the demand of solar power, or 6 GW, whereas in 2014 they produced 75%, but only 5.3 GW. Besides, only twelve out of forty-four countries total more than 1 GW. The cumulative on-grid capacity of Europe was 92 GW. However, in the United Kingdom, solar energy installed during 2016 was half as of 2015. The decline in solar panel installations was attributed to the government's significant reduction in incentives for residential solar uptake and the discontinuation of solar farm subsidies (38). In addition, solar energy is not limited to fulfilling the electricity demands for residential or industrial sectors; instead, it may accomplish the rapidly increasing electric vehicle-based transport industries (39). For European countries are primarily technological driven, there is an emphasis on industrialising and deploying electric vehicles (EV) to reduce carbon emissions from fossil fuel-based vehicles. As stated in the Europe Roadmap 2050 for energy, 100% electrification of light-duty vehicles (LDVs) and medium-duty vehicles (MDVs) is set as an achievable target which suggests using solar energy for charging systems of electric vehicles (40).

As for now, there are numerous diverse policy schemes for distributed solar generation in Europe. For example, some European countries implement a tax levy for selling electricity produced from conventional resources; however, electricity produced from green sources is exempted from this tax levy. Some countries are reducing excise duties on solar energy equipment to encourage solar uptake. In Austria and Germany, self-consumption schemes have been implemented both for residential and commercial solar systems. A few European countries, such as Portugal and Italy, have employed net-billing schemes but still have partial accomplishment, while the Netherlands has introduced net-metering for domestic buildings. Furthermore, it is found that a tax credit may significantly decrease the solar power typical life cycle budget. Based on this, currently several European nations employ this form of tax enticement. Additionally, a few countries have legislated reduced property tax to stimulate the uptake of solar energy (41).

1.7 COVID-19 Impact on Global PV Market

Due to the current globalisation era, the coronavirus (COVID-19) outbreak in Dec 2019 rapidly engulfed the world at a breathtaking pace by the middle of February 2020 and created a pandemic situation in the whole world. This pandemic has cast a pronounced threat to human health and has instigated colossal damage to the global economy, particularly to the supply chain of industrial sectors and their related financial markets (42). During the epidemic situation, the capability of companies and industries to contend supply chain disruptions due to enforced lockdowns were affected drastically. Most businesses and industries couldn't be relocated to remote areas during this short period of massive virus spread across the globe. In energy sections, renewable energy is managed well compared to the conventional energy sources; however, numerous uncertainties, transport interruptions and sudden decline in employability scattered the overall renewables value chain and end-use sector.

According to the International Renewable Energy Agency (IRENA) study, the renewable energy sector created more than 11.5 million direct or indirect job opportunities worldwide. In particular, solar PV technology created the most jobs, with 3.75 million jobs worldwide until the COVID-19 outbreak (43). Despite the COVID-19 epidemic, the renewable energy sector managed to grow until early 2020 because of the previously implemented policies and limited availability of equipment in stock. However, the complete understanding of the direct or indirect impact of the COVID-19 on the solar energy division is not yet clear, as the global supply chain in all industries was impacted drastically by repeated lockdowns and international travel restrictions (44-46). Specifically, recent studies testified the significant deferments in the supply chain of solar energy equipment availability and installation occurred due to this pandemic situation (47, 48). As the world relies on China to supply 65-75% of the solar energy equipment in the international market, China's industrial and supply chain disruptions impacted the global solar energy installation targets (46-48).

Regarding the impact of the COVID-19 epidemic on solar power technology, a recent study states that governments are granting more capital to fight the COVID-19 pandemic, which indirectly cutbacks the clean energy activities funds. Consequently, retailers of various clean energy technology have reduced their functional capacity and replaced workers, damaging the progress of clean energy technologies (22). Furthermore, the COVID-19 pandemic has unsettled clean energy advancements by undercutting the financial grants for technological research and business development. Similarly, strict lockdown rules have also affected production activities, which caused an increase in material prices, although they have been expected to be temporary (47).

In another study, the short term and long term bearings of the COVID-19 on the energy market have been examined, which suggest that the energy sector may continue to rise for a short period while the long-term impact depends on the lasting period of pandemic (49). Another study reported that the first plunge over the last three decades in the solar power equipment demand came about in 2020 by 16% (50). The COVID-19 pandemic has unquestionably disturbed the price determination model of the renewable energy industries, services, and related businesses, which as the energy sector is crucial for worldwide economic growth. (51-53). In addition to supply chain disruptions, some analyses aimed at understanding the stock market response to the pandemic proved that unforeseen incidents such as natural catastrophes could impact the stock market (54). Similarly, the COVID-19 pandemic, because of implementing a government's prevention policy for COVID-19, many solar power resources share prices have changed, conforming to at length parameter estimation (53, 55, 56). Some studies indicate a co-integration relation between COVID-19 cases and the solar businesses share prices and between COVID-19 restrictions and their share prices (52).

1.8 Outline of the thesis

Chapter 1 highlights the capacity of global energy concerns, stressing the growing demand for electricity and the significance of renewable power generation. It examines solar cell technology, solar energy advancement globally, particularly in the United States and Europe, and the effects of the COVID-19 pandemic on the solar energy industry. Finally, the chapter emphasises the significance of the study in sustainable energy transition.

Chapter 2 discusses the solar energy industry in Australia, emphasising the advantageous environmental circumstances that make it suitable for solar energy production, given the abundant sunlight. It examines market trends, technical improvements, government assistance, and the industry's response to the pandemic. Moreover, it evaluates the social and economic variables to comprehend the prospects and obstacles of solar energy uptake in Australia.

Chapter 3 thoroughly reviews previous studies on the rooftop solar energy industry. It investigates the relationship between the solar energy market and key effecting parameters such as GDP, demographic variables, advertising, and costs. The study examines how socioeconomic factors and economic variables influence the adoption of solar energy. It also investigates the role of legal frameworks and environmental factors in this process. The chapter culminates by evaluating the impact of the COVID-19 pandemic on the Australian solar energy markets, explicitly examining its effects on businesses, capital markets, logistics, supply chains, and transportation.

Chapter 4 explores various statistical models employed in forecasting solar energy uptake and analysing its responsible influencing factors, encompassing Linear Regression, Logit, Probit, SEM, Spatial Econometric Panel, Decision Tree, Time Series, Geographically Weighted Regression, and Cross-Sectional Models. The chapter delivers insights into each model's features, uses, and limitations, assisting in choosing a suitable model based on research goals and data characteristics.

Chapter 5 explains the study's methodology, explicitly outlining the objectives and selected econometric approach, the cross-section regression model. The study aims to evaluate the impact of COVID-19 on the uptake of residential solar in Australia, considering the important socioeconomic and demographic aspects. The methodology entails stringency level associated attributes, duration of lockdowns, and COVID-19 instances to systematically examine the impact of the pandemic on the adoption of solar energy. The chapter also states the reliable sources used for data acquisition, including the Australian Bureau of Statistics, the Australian Government Clean Energy Regulator, and APVI.

Chapter 6 introduces the preliminary analysis using New South Wales data to examine the model's effectiveness, and modifications were implemented to strengthen the model using the insights acquired from the test analysis. The chapter elaborates on the approach used to account for the transient nature of the pandemic, employing variables including the COVID variable, demographic parameters, and socioeconomic indicators, yielding intricate conclusions regarding residential solar adoption during the pandemic.

Chapter 7 addresses the refinement of the approach for the National model developed in the light of the preliminary analysis results. This involves substituting the COVID variable with the Lockdown duration variable, optimising the model's accuracy. Additional models are added to the study to determine the lockdown's short-term and medium-term impacts, including interaction models to inspect the effects of COVID-associated socioeconomic and demographic variables. Furthermore, a construction ban variable is included to assess the construction industry's forced shutdown effects on residential solar adoption.

Chapter 8 presents the National model analysis results. In Queensland, Northern Territory, South Australia, and Tasmania, which had shorter lockdowns, home solar adoption was positively correlated with active lockdown length. The pattern differs in New South Wales and Victoria. The data also shows how the construction restriction affected different locations. During the pandemic, separate dwellings, older age, larger households, more education, and small-scale renewable scheme ratings drive solar uptake.

Chapter 9 presents the study's conclusions, policy propositions, and limitations. The research suggests that active lockdown duration curtails rooftop solar uptake in Victoria whilst increasing it in New South Wales and the Australian Capital Territory. Solar deployment was impeded by university-level education and marital status. In contrast, high-school-level education, household demographics, and government policies promoted it. The research recognises aggregated data limitations and proposes policies to stimulate adoption and future research paths.

Since the study aims to inspect the COVID-19's effect on solar PV deployment in Australia, an unprecedented global crisis, the methodology of the study is determined by an extensive analysis of the existing literature review spanning a broad spectrum of research objectives focusing on the global solar energy market, including its development trajectory and the associated support policies, a rigorous examination of the Australia residential solar market framework, scrutiny of global and Australian key influential factors affecting the uptake and subsequent review of the potential pandemic effect on the uptake. The sequential steps in this research progress is shown in Figure 5.

The variables are selected given their significance in the literature for the uptake, and the COVID-19 associated factors that may have affected the uptake during the pandemic. Given the nature and availability constraints of the data, the cross-sectional regression model is chosen for this study with additional discrete models utilizing interaction terms for individual control variables to illustrate the COVID-19-associated effect of these variables on the uptake. Statistical tests are used to validate the model's robustness.

Additionally, the model is tested by an initial analysis that uses data from New South Wales, the most populous state in Australia. Based on the findings of the preliminary analysis, a national model for the whole of Australia is created, incorporating additional models for comprehensive investigation and making the necessary amendments. The findings demonstrated the effect of COVID-19 on household solar uptake and the direct and pandemic-related relationship of the control variables with the uptake during the pandemic as per the study's objectives. Conclusively, the study identifies the driving factors and the barriers to the adoption of residential solar during the pandemic while suggesting policies for market expansion. Moreover, by highlighting its limitations, the study paved the path for further research.

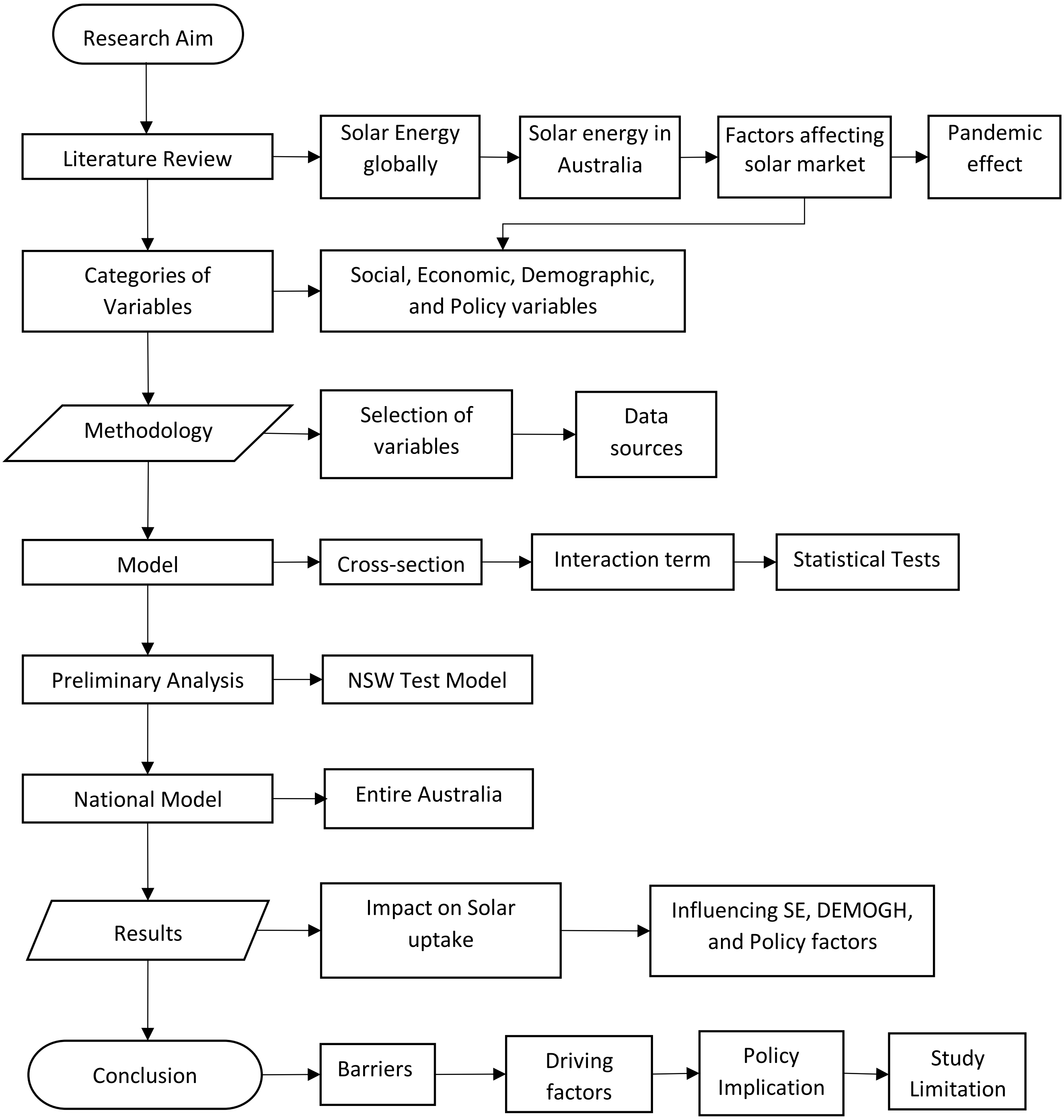

Figure 5. Project Methodology Flowchart.

1.9 Significance of the project

Australia is currently facing worsening climate change catastrophe droughts, flooding, storms, and bushfires draining the economy and declining productivity, damaging the properties, and spiking mental and physical health expenses (57). Australia contributes roughly 1.3% of the total yearly world greenhouse gas (GHG) emissions. In alignment with the Paris Agreement, the nation has committed to reducing these emissions by 43% compared to their 2005 levels. Additionally, individual states within Australia have set their own GHG emissions reduction targets, with New South Wales targeting a 50% reduction, the Australian Capital Territory aiming for 65-75% compared to 1990 levels, Queensland targeting a 30% reduction, Western Australia striving for an 80% reduction, and South Australia aiming for a 50% reduction. Tasmania has already achieved its net-zero emissions target in 2015.

Australia has made significant commitments to international agreements and working parties, aiming to generate 82% of its electricity from renewable sources by 2030. To achieve this, the government has developed various strategies and plans. These initiatives include the National Electric Vehicle Strategy, the National Reconstruction Fund, which supports the transition from fossil fuels, and the Rewiring the Nation program dedicated to boosting household solar energy deployment by investing in community batteries and solar banks. Notably, Australia has already achieved a 21.6% reduction in emissions and boasts the highest level of residential solar uptake globally (58).

This project's significance lies in its contribution to the broader discourse on climate change mitigation. It offers valuable insights into how unexpected disruptions, such as the COVID-19 pandemic, can impact the adoption of renewable energy. It underscores the importance of adaptability and resilience in achieving climate targets, both domestically and as part of the global effort to combat climate change.

In addition, implementing solar panels in Australian households yields substantial advantages for the broader society. One of the significant benefits is the favourable influence on individuals and families. Solar panels offer a pragmatic solution for lowering electricity costs, relieving financial strain on households (59) (60). Homeowners who generate their own power reduce their susceptibility to potential price increases in conventional energy sources, protecting their financial stability (61).

Preluding the desideratum for a zero-emission clean environment and rooftop solar empower households to play their role in achieving this goal individually by saving their energy bills which is another significant edge (62). The residential solar PV demand makes the Australian solar market sustain its position among the world's top ten photovoltaic markets (63). Moreover, photovoltaic systems, based on their off grid on the point of demand power generation capabilities saving transmission and distribution costs, have unparalleled significance, especially for remote areas. Apart from its growing dependence on government policies, several investigations, data analyses, and mathematical models have been done to understand the spatial distribution and the socioeconomic factors associated with rooftop solar PV adoption for global and Australian solar energy markets (64-69). The study aim to re-evaluate the key socioeconomic and demographic factors in the existing literature in the light of COVID-19 as a Force Majeure Event with continual low PV system costs, rapid escalation of work from home configuration, and a change in domestic spending on upgrading households to evince the vulnerabilities and gaps in the current solar PV market (70). Discerning the area of concern and strength through this study can help frame the solar energy policies concentrating on eradicating the barriers to solar PV diffusion and rejuvenating and maintaining the adoption drivers to residential solar uptake.

The study indicates that extended lockdowns have had a negative effect on the uptake, while shorter lockdowns have resulted in increased uptake and no discernible influence of restrictions outside the lockdown on the uptake, suggesting that governments should avoid implementing prolonged lockdowns to mitigate a pandemic outbreak. Instead, they should consider implementing more comprehensive and stringent restrictions to control the disease spread without negatively impacting uptake. Furthermore, the study suggests that construction bans, especially the shutdown of residential solar installations, should be avoided. This is because installations can typically be carried out without any physical interaction with residents while maintaining physical distancing among workers.

However, it is challenging to predict the potential results for other countries with different COVID-19 policies. The number of COVID-19 cases can be another factor affecting uptake in the context of the pandemic. Still, it was excluded from this study due to the unavailability of data. Additionally, it is imperative to acknowledge that number of cases in Australia was relatively small compared to many other countries, where the numbers were significantly higher and could have impacted uptake.

Nonetheless, other studies have suggested a negative impact of the pandemic on the global solar energy sector. Factors such as solar panel equipment delays, supply chain disruptions, and construction delays have been identified as contributing to this impact (71) (72) (73). Remarkably, the effect of COVID-19 policies on uptake in other countries is yet to be analysed.

Chapter 2: Solar energy in Australia

2.1 The geographical location of Australia for solar energy utilisation

Due to the geographical location, Australia receives the highest solar radiation intensity per square unit (4-6 kWhm−2) estimate, around 10,000 times its annual energy intake. This radiation intensity governs Australia substantially by implementing CH3NH3Pb0.75Sn0.25I3 perovskite solar cells and contributing to a low carbon emission environment (74). In this way, Australia has a very high potential of replacing fossil fuel energy with solar energy both at the industrial and residential levels by installing large-scale solar farms and rooftop PV systems. The Australian government has already encouraged promoting the solar energy market by subsidising more than 1 billion dollars in various industrial, market, and research sectors. The business and consumer policies enhanced uptake of solar systems on dwellings in Australia from an overall 0.2% average in 2007 to more than 28% until 2021, as shown in Figure 6. Especially in the last couple of years, Australia's solar energy generation capacity soared significantly, with the current total capacity of more than 500GWh power. Although this percentage is encouraging, more than 70% of the electricity demand is being fulfilled using fossil-fuel-based power plants that continuously release greenhouse gases in the Australian environment. Given the challenges of restraining carbon emission and irrepressible and disastrous factors such as severe bushfires, the requirements and goals of achieving an eco-friendly environment have become even more challenging and important. In addition to the environmental challenges, Australian solar energy is a billion market and directly impacts the Australian economy.

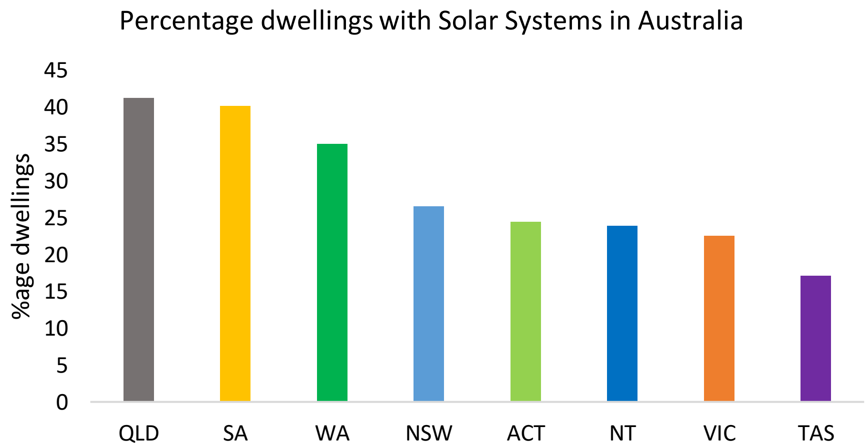

Figure 6. Percentage dwellings with the solar system in Australian states and territories. Currently, Queensland (QLD) has the highest % of dwellings with installed solar systems, followed by South Australia (SA), Western Australia (WA), New South Wales (NSW), Australian Capital Territory (ACT), Northern Territory (NT), Victoria and Tasmania (TAS) (75).

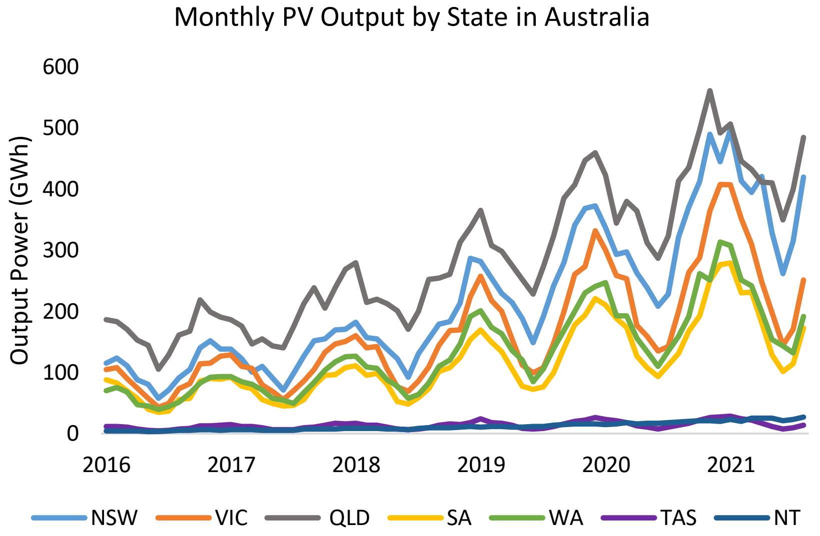

Figure 7. The monthly PV power output of different states of Australia with higher PV production. The higher and lower peaks represent the seasonal solar production, i.e. higher PV output in summer and lower in winter. Overall, the PV output peaks show an upward trend. Data accessed from reference (76).

2.2 Importance of solar electricity generation in Australia

Reducing the levelized cost of electricity holds a distinct position in Australia's critical policy matters. Plentiful efforts to implement energy and environmental policies have been obstructed due to fear of increasing retail electricity prices. In Australia, within this policy discussion, solar energy is a principal factor for generating electricity persuading the electricity prices. In the last couple of years, when the overall electricity prices soared, which also coincides with the increasing amount of electricity generation through household and commercial PV installation, there is a primarily held misconception that this increase in the electricity prices is linked to the enlarged diffusion of solar energy investment into the wholesale electricity market. However, it has been investigated by mathematical model analysis that wholesale electricity prices have been reduced by solar generation, and it would have been higher than what they are at present. Consequently, it is anticipated that these moderating outcomes of utilising solar energy on wholesale electricity prices are expected to persist in the forthcoming years (77). These investigations may possess a significant implication of Australian solar energy policy, which suggest that Australian solar energy business stakeholders and consumers should not pull out support and interest to generate PV electricity based on these improbable facts.

2.3 Solar Energy Business in Australia

Business is generally defined as a framework or mechanism which gives the concept of buying and selling implemented by consequential demand and supply factors of an item, facility or service, and a financial transaction. This generation of energy or electricity is the demand side for the solar energy business, while solar energy equipment and installation framework are on the supply side of the solar energy business. As Australia has an excellent geographical location in terms of solar irradiation, there is an incredible potential for a successful solar energy business in Australia if implemented with adequate business policies. In this regard, it is considered that most of the energy projects or related businesses are highly dependent upon governmental policies, and the solar energy business is a primitive example. For most impending PV system policymakers, ecological factors are the primary business development drivers rather than economic factors, thus signifying the importance of careful study for policymaking to keep the solar energy business alive. With the significant advancement in the Photovoltaic (PV) technology, the Australian government introduced business investment and subsidies policies to enhance uptake of solar energy systems both for commercial and residential users; however, it has been demonstrated that the affordability of PV system installation is not the main contributing factor for the users. Therefore, to meet the high demand for electricity consumption, maintain the solar energy usage momentum, and achieve the Paris agreement targets, a major reshape in the strategic priorities and business development policies is required by both the Australian government and the public sectors. Some major schemes that have significantly boosted the solar uptake in Australia are as follows:

2.4 Tradeable energy certificates for the energy business

A critical component for the Australian renewable energy policy scheme is generally called the Renewable Energy Target (RET) scheme initiated in 2001 to decrease the environmental release of greenhouse gases from fossil fuel-based electricity and generate some part of electricity capacity from renewable, sustainable resources such as solar energy. The mechanism of this RET scheme is to permit the owners of solar power stations to create tradeable energy certificates for every megawatt hour of the energy produced by a clean energy source such as solar energy, provided that the solar PV system is installed by solar companies or business professionals approved by clean energy council (CEC). These certificates are generally called renewable energy certificates (RECs) and are further classified as small-scale technology certificates (STCs) and large-scale technology certificates (LTCs). In business terms, where the supply and demand framework is essential for business transactions, these certificates create a 'supply' side of the solar energy business. The electricity retailers, registered agents or solar installation companies can purchase these certificates from the owners whose quantity is based on the estimation of generated solar energy over the lifetime of solar systems, creating a 'demand' side of the energy business. As a return, the retailers can provide a delayed cash payment system or one-off discount on the initial installation cost of the solar system, which is sometimes also termed as the Australian federal solar rebate. The solar system owners also can sell these certificates in the STCs open market at market value or a fixed rate of $40 per STC through the Clearing House. Additionally, electricity retailers can surrender these certificates to the Clean Energy Regulator to fulfil their legislative requirement to remain in the solar business.

In 2011, the scheme was divided into two categories: Small-scale Renewable Energy Scheme (SRES) and Large-scale Renewable Energy Target (LRET), depending on solar energy capacity generation. This scheme has been proven a great way of subsidising the solar energy business, enhancing the solar energy business across Australia. SRES previously covered a larger volume of solar system installation. Another technical framework of the SRES was that the higher the solar radiations received by the postcode, the higher the subsidy for rooftop PV system installation, which meant to increase the overall solar uptake. Interestingly, a comparative study of solar power generation of diverse geographical zones advocates that areas eligible for the highest subsidy may not necessarily have a higher solar installation rate (48). The LRET scheme was designed to generate a financial enticement to set up and grow green stations, including wind farms, hydroelectric power plants and solar farms, to achieve the target deadline in 2020. Until 2019, despite the difference in the population where the US is 13 times larger than Australia, the number of solar PV installations among both countries was the same (78). These figures were quite promising until the historical and widespread bushfires in Australia. This bushfire burned more than 2500 homes and billions of trees over 6 million hectares across Australia and further increased the necessity of installing new solar systems (79).

2.5 Market Incentives

Another approach to boost the uptake of the residential rooftop solar systems through a generously subsidised policy mechanism is called a feed-in Tariffs (FiTs). This subsidy scheme is initiated to support clean energy technologies such as solar energy by granting a payment per kWh for the electricity generated by a renewable energy resource and fed into the electricity grid. FiTs schemes were introduced to kick-start the solar energy business in Australia with generous selling rates of electricity to the electricity grid. As the solar energy equipment prices have been declined by around 80% since 2008, FiTs rates have also decreased depending upon several factors such as the solar systems geographical location in Australia and electricity retailers. Currently, these FiTs are generally lower in dollar value than the electricity purchased from the grid; thus, an offset remains on selling and buying the power from and to the electricity grid.

These schemes began with the inception of premium FiTs in several states. For instance, New South Wales (NSW) initiated its Solar Bonus Scheme, offering a generous gross FiT of 60 cents per kilowatt-hour (kWh) from January 2010 until October 2010, which continued at a reduced rate until December 2016. Similarly, Victoria, in November 2009, introduced a Premium Feed-In-Tariff for Solar, which continued until December 2011 and transitioned into other FiT schemes. Queensland launched its Solar Bonus Scheme in June 2008, which continued until July 2012, providing net FiTs. Subsequently, several regional schemes were introduced. South Australia (SA) implemented its Solar Feed-In Scheme in July 2008, which extended until September 2013 for some participants and until June 2028 for others. The state also introduced various minimum retailer payment schemes. Western Australia (WA) in July 2010 implemented its Solar Feed-in-Tariff, lasting until July 2011 for some installations.

Additionally, the state introduced the Renewable Energy Buyback Scheme through Synergy and Horizon. Tasmania, on the other hand, established the Aurora Energy Net Metering Buyback Scheme as early as July 2000, evolving over the years with varying rates and duration. These premium FiTs were subsequently replaced by various other FiT schemes in different states, marking a shift in the approach to incentivizing residential solar energy generation and grid feed-in. The Australian Capital Territory (ACT) implemented the ACT Small-Scale Feed-in Tariff for different kW ranges and encouraged voluntary retailer contributions starting from July 2011. In the Northern Territory (NT), the Solar Buyback scheme through Power Water/Jacarana Energy Retail operated from June 2013 onwards with a gross FiT policy (27), (21)

Although the governmental subsidies programs may seem to enhance the countrywide solar uptake, it is observed that capital subsidy programs such as RECs work differently in different situations. As a result, capital subsidies may have less impact on the PV system purchasing, and the availability of FiTs may contribute higher towards the consumer's decision to purchase PV systems (80). Additionally, it is also found that the affordability of the solar system installation may not be the primary solar uptake factor (81) as a recent study demonstrates that the solar PV installation rate in Queensland is almost identical in the five top socio-economic areas and the lowest five. Furthermore, it is stated that several other traits such as household size, number of occupants, property rights issues and physical human capital also affect prioritising different sectors both for policymakers and consumers (82). Although this study highlights significant aspects, there is a lack of extended analysis of the performance and sustainability indicators as per the new priorities during the pandemic, such as bushfires and virus spread.

Based on several investigations both for regional and urban Australian regions, it is argued in order to achieve a more balanced growth of regional solar power, a diversified regional energy policy is required (83), (84). In Australian states such as Queensland, Western Australia, and South Australia, subsidies such as Feed-in Tariffs (FiTs) can continue to work effectively. In the Australian Capital Territory (ACT), Victoria (VIC), and New South Wales (NSW), where compact population and living circumstances are present, conventional residential solar PV may face space constraints. However, an alternate option of employing centralised photovoltaic power stations or solar panel walls or solar farms may be more efficient. In the Northern Territory (NT), where the population is dispersed throughout the state and lesser people with lower solar energy information programs, the local social variables may not encourage the widespread use of PV products and technologies (85). As it has been found that advertisement and social media have a significant impact on increasing awareness and benefits of solar energy, expanding a community focused promotional campaign to stimulate the solar panel diffusion may compensate for the absence of peer influence and enhance the adoption rate. Moreover, any singular rooftop solar PV strategy may not be effective in Tasmania, suggesting that a mix of policies considering the socio-economic status of the local community could enhance solar adoption. Overall, as there are different socio-economic variables for Urban and Regional Australia, a concentrated policy framework should be adopted instead of a universal framework.

Despite that more comprehensive research is required to recognise the motives of this regional disparities. Future research needs to acquire further comprehensive data analysis on a full scale, for instance the fundamental structure of individual family, integrated with a survey or questionnaire to authenticate a few outcomes and assumptions of this study. Moreover, multiple socio-economic factors influence the regional differences in residential solar diffusion rates and internal relationships between socioeconomic characteristics of population apparently exists. Therefore, it is required to use more sophisticated approaches, like as system dynamics, to understand how socioeconomic factors interact to affect the result of solar uptake.

2.6 Solar battery rebate or virtual power plants

As there is a difference in dollar rate buying and selling the electricity to and from the electricity grid, solar electricity producers sell electricity at a lower rate than they buy from the grid. This business framework might not be considered encouraging for some solar system installers. This technological system requires electricity storage batteries with a high initial installation cost with a payback period of more than ten years. In this regard, even though every state government has introduced battery rebate programs that can improve the affordability of solar batteries, many households have yet to take advantage of these incentives (86). It's worth noting that the adoption rates of household-level storage systems remain at a notably low level, suggesting that there is significant room for growth in this sector (87) (88). As governments do not have unlimited financial resources to reduce the battery cost, electricity retailers have set up virtual power plant (VPP) systems. Technically, VPP is an interconnected or linked network of several solar batteries from different solar systems installed at various locations that optimise the supply of electricity stored in batteries to multiple locations/buildings and have less reliance on utilising high-cost grid electricity (89). From a business perspective, the electricity retailers provide the rebate to the consumer to purchase solar batteries or VPPs. Using VPPs, the consumer can power their home or businesses both day and night, reducing the power burden on the grid.

2.7 Effect of socio-economic variables on Australian solar energy market

Socio-economic variables are the variables of a society that relate the social status of a person or community to economic development or contribution. People's socio-economic status is measured in numerous ways, most frequently as education, social status, or income. For commercialised industries such as residential solar energy systems, these variables are critical and significantly influence the solar energy market. Several investigations, data analysis and mathematical models have been applied to the socio-economic data and solar energy market to understand the spatial distribution and socio-economic factors associated with residential solar PV diffusion for global and Australian solar energy markets (21, 68, 81, 84, 90-106). Among these studies, the outcomes of the essential variables for instance disparities in the geographic distribution of solar energy assets, economic growth, population size, and built environment for residential solar panel installation has been found implicit to socio-economic factors. This study on Australian solar energy market drivers and socio-economic factors revealed the spatial aggregation of solar cell installation. It also segregated areas of high and low concentration regarding the installation rate (the percentage of residential solar uptake) through spatial autocorrelation analysis (107).

Similarly, another economic correlative study of the distribution of solar energy installation in Australia suggests that solar penetration is higher in postcodes with more significant shares of moderate-income households. Furthermore, it is found that the rooftop solar installation rate is higher in the postcode with a higher proportion of mortgage holders (82). As there are differences in the finding of the effect of socio-economic variables on solar energy uptake and business, there is a need to reconsider and re-evaluate these variables for the Australian rural and urban region and draw broad conclusions that could facilitate policymakers to reshape the framework for the solar energy business. Especially after the recent COVID-19 pandemic, there has been a substantial change in the socio-economic variables of the Australian community that might have impacted the solar energy business and consumer uptake. In light of COVID-19 pandemic restrictions, these socio-economic variables should be investigated in detail to understand and reshape the solar energy business.

2.8 COVID-19 pandemic effect on solar energy business in Australia

Similar to the global impact of the COVID-19 epidemic described in section 4.4, Australian communities, industry, supply chain, transportation, employment and retail services were hugely impacted. All these factors affected the work, daily lifestyle and overall socio-economic status involving the solar energy market. People tend to stay at home due to strict lockdowns. All the industries that required on-site equipment installation, such as solar energy systems and related businesses, were affected drastically. From solar energy business growth, the number of solar system installations is a good indicator. As per the latest data from the Australian PV institute graphed in Figure 8, which is the number of solar system installations in a calendar year for the size range up to 14kW capacity, typical for residential dwellings, continued to increase as data depicts higher values each year, showing an overall upward trend. The number of solar system installations peaked until the lockdown restrictions were enforced at the start of 2020. After this peak, the number of installations dropped from approximately 23000 installations to less than 10,000 due to recent COVID-19 lockdown restrictions. Data shows that the number of installations from 2016 to 2018 for PV systems of capacity 6.5kW to 9.5kW has a continually rising trend until the end of 2018, which has a sharp drop since then. This sharp drop continued to decline during the COVID-19 lockdown restrictions. To better understand the continual decrease in 2021, it is mandatory to investigate and find the reasons or factors behind the sharp drops before the COVID-19 pandemic. This investigation could better understand the reasons or factors behind the continual decline of installations during the pandemic restrictions. It may help prepare better for the upcoming unforeseen pandemic.

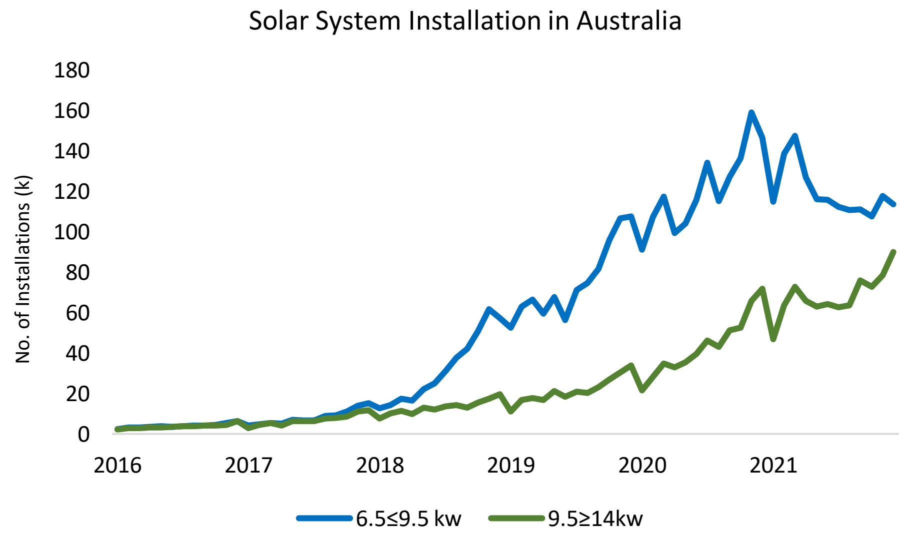

Figure 8. The Number of PV system installations in Australia per calendar year for PV systems in the range of 6.5kW to 14Kw, which is a typical PV system size for dwellings in recent years. For PV systems of capacity 6.5kW to 9.5kW, no. of system installations has continuous rise from 2016 to late 2018. After 2018 to mid-2020, the overall trend is higher but with volatility. The trend PV systems of 9.5kW to 14kW capacity is relatively smoother than for 6.5kW to 9.5kW but in a consistent, sharp drop during the strict COVID-19 restrictions across Australia (108).

Chapter 3: – Literature Review

3.1 Factors affecting the solar energy market

The residential solar market is a complicated and dynamic market, susceptible to a diverse range of factors that affects numerous industries. Governmental policies and incentives have a significant impact on the solar market's trajectory. The implementation of policies such as subsidies or tax breaks and tax credits can significantly diminish the expenses associated with solar installation. This, in turn, can render solar technologies more economically accessible to households and businesses, thereby stimulating demand. Another important factor is technology, which constantly redefines what is possible in the residential solar market. The cost-performance index of photovoltaic systems is always improving because of advancements in battery storage capacity, efficiency, and solar inverter technology of solar panels, making solar PV-generated electricity an increasingly appealing alternative for energy customers.

The state of the economy also has a substantial impact on the residential solar market. The rate at which solar technologies are adopted can be affected by various factors, including electricity prices, GDP growth rates, and the capacity for capital investment. For example, individuals and companies may be more likely to uptake solar PV during times of economic growth. Environmental factors significantly influence the adoption of solar energy. The growing concern about climate change and its consequent impacts has increased public inclination towards sustainable and clean energy sources, specifically solar power. The growing awareness and concern for the environment can potentially drive the market demand for solar installation potentially affecting federal and State government policies associated with the growth of renewable energy sources.

Lastly, social aspects must also be considered. Various factors, including education level, total household income, individual perceptions concerning the uptake of residential solar PV, and social conventions, can influence the adoption of solar technology. For example, areas with a higher proportion of disposable income or have a greater share of the population with better education and awareness of the advantages of solar PV might be more willing to adopt residential solar.

In summary, an effective comprehension of the solar market requires an in-depth understanding of these numerous influences. Recognising the complex relationship between these factors and residential solar diffusion is essential for policymakers and stakeholders to reshape the residential solar market by promoting solar adoption, developing policies, or investing in the advancement of solar PV technologies. In regards to solar energy market, a list of most influential socio-economic and demographic variables is described in Table 2.

3.1.1 Literature Background

The literature review was meticulously conducted to ensure a comprehensive exploration of the multifaceted aspects of the research question. This methodological approach was deliberately chosen to encompass all vital components required for addressing the research questions of the study. It involved an analysis of the global solar energy sector, its contemporary advancements and the governmental policies that have played a pivotal role in shaping it. This global analysis was then compared with the unique dynamics of the Australian residential solar market. A detailed examination of the residential solar market in Australia was undertaken, with a particular emphasis on factors influencing the uptake of residential solar. This encompassed an in-depth exploration of government support policies and socioeconomic and demographic factors.

Following the identification of these influential factors, a comprehensive review was conducted to evaluate their influence on both a global scale and within the context of Australia as shown in Table 1. Additionally, to understand the potential implications of the COVID-19 pandemic on residential solar uptake, an investigation was executed to assess how the pandemic may have affected various aspects of the residential solar market framework.

Table 1. Literature review criteria

Heading	Remark
Research domain	Solar energy; Residential solar PV; Solar energy worldwide; Australian Residential Solar Market; Residential solar uptake affecting factor globally; Residential solar uptake affecting factor in Australia; COVID-19; COVID-19 impact.
Search string	Solar PV, Solar PV adoption factors; Australian Residential Solar Market; Solar energy policies Australia; COVID-19; COVID-19 effect/impact;
Publication Type	Academic journals, book chapter, and conference proceedings indexed in Scopus & Web of Science, Official Reports and Media releases from Renewable energy bodies around the world .
Relevance	Articles articulate residential solar energy; Solar PV adoption; Solar PV diffusion, COVID-19; Socioeconomic variables effect on solar PV uptake, Demographic variables effect on solar PV uptake, and Small-scale renewable energy/solar energy policies.
Time	Last two decades

In summary, the research methodology for this literature review involved a thorough and methodical analysis of existing literature to gain insights into the factors driving residential solar adoption in Australia. It also delved into the possible effects of the COVID-19 pandemic on these factors, covering a wide spectrum of research objectives while not strictly adhering to the structure of a systematic review.

3.1.2 Solar energy market and GDP growth

It is mainly assumed that enlarged industrialisation consequences in growing job opportunities that may result in the form of better GDP of a country. From the data over the period 1999-2015, an economic study has been performed to examine the connection between the solar energy market and economic progress of the top 10 countries by solar power installed capacity (China, United States, Japan, Germany, Italy, India, United Kingdom, France, Australia, and Spain, sequentially). This study suggests that solar power generation has not influenced the overall GDP and found no connection between GDP and solar energy production (109). On the contrary, while making policies in these countries, acknowledging the significance of solar energy in reducing environmental problems is essential. Several underlying critical reasons behind this may explain the stagnant behaviour of this GDP growth; however, the main factor is the increased population and energy demands that balance the equation between the solar energy market and GDP growth. In previous paragraphs, the technological and scientific efforts behind the various solar battery innovations have been discussed. Other factors such as financial expense aspects of installation, commissioning and deployment of solar systems, local and global policies have played a significant part in advancing specific innovations. They will keep up this trend so in the future. Rising general awareness for clean and sustainable energy sources requirement supported the continuous R&D of solar battery innovations. Material shortages and the amount and pace of the mandatory investment possibly also hinder efforts to level up the production of current technologies (110).

3.1.3 Advertising and social media impacts

Generally, the researchers study the academic and patent literature or data to classify and observe the progress of evolving technologies from a technical point of view; however, they rarely employ advertising and social media campaign data. In modern times, as social media casts an immense effect on people's consideration and disposition towards an explicit project or general topics, examining the social media data might govern deep insights to understand and forecast the business and usability trends of the solar energy market. Lately, a data analysis methodology has been performed by analysing the data of a social media platform called 'Twitter' and patents filed in the area of the solar energy business. Specifically, this study proposed a system performing analysis on patent data and data from Twitter to assess the development of leading technologies and categorises the forthcoming technological trends from a business and technical viewpoint. By examining the Twitter and patent data associated with a specific category of the solar cell named perovskite solar cell technology, it is proven that this sort of data can assist in improved monitoring and comprehension of the technological development trends that may encourage the solar energy market and business indicators, and hence overall electrical power generation capacity (111).

3.1.4 The cost factors

The cost of the entire solar energy system mainly consists of PV modules or solar cells; there are other electronic types of equipment involved that affect the overall project cost. Among all the semiconductor-based PV cells, organic solar cells perhaps are economical. However, the cost of the PV panels is merely one portion of the overall installation cost as it involves other equipment. This equipment are inverters, used to transform the direct current from solar panels into 120V/240V alternating current, and storage batteries that store the converted solar energy, which may be utilised at night. Even with technological innovations in the manufacturing of batteries, their initial cost is still high. At present, various research to produce cost-effective batteries is ongoing commercially. Still, no significant reduction in the price of batteries appeared. Alternatively, for decreasing the cost of electricity generation through solar power, combining it with other renewable energy resources such as wind energy and geothermal energy may resolve this issue (15). Additional costs include installing the mechanical frame for mounting the solar cells, an intelligent sun-tracking system, electrical wiring, distribution electronics, and panels recycling. The natural bottom line in terms of commercial use is called the levelized cost of electricity (LCOE): cost generated per unit of electricity to recover the system's lifetime cost. Although some cost-effective panels might offer one way to reduce initial installation cost and the LCOE, many pieces of research are underway to enhance the other key economic factors: power efficiency and overall lifetime.

Globally, solar PV is currently a prevailing technology, contrary to various other established renewable technologies. Reduced cost is due to technological innovations and policy developments. While the overall equipment costs have declined, other factors such as cutbacks in capital costs, operation and maintenance, and balance-of-system drivers have significant importance for further cost reduction. Additionally, further decrease of LCOE requires advancements in various sectors such as enhancing the economic scale, efficient and robust supply chains systems, continual technical innovation in solar panel mounting in different weather conditions, electricity distribution systems, encouraging commercialisation and policies, public awareness and advertisement through mainstream media with an emphasis on generating solar energy.

In the last decade, cutbacks at the solar panel market's cost were primarily influenced by a drop-in module price, given 18-22% learning rates. However, with the present-day module prices ranging between USD 0.5/W and USD 0.7/W, a future decline in the cost of modules will impact to a lesser extent than previously to overall installed expense reduction potentials, even with aggressive expansion in solar PV uptake. Overall, by 2025 concentrating solar power (CSP) technologies and solar PV can cut the global weighted average electricity price by a minimum of 37% and 59%, respectively, as reported by the International Renewable Energy Agency (IRENA) (112). The report summarises the globally collected latest data and mentions that 82% LCOE of utility-scale Photovoltaic power plants dropped from 2010 to 2019, approximately USD 0.31/kWh in 2019, including a decline of 13% year-on-year in 2019, while for CSP, this cost reduced from USD 0.346/kWh to 0.182/kWh (113).

3.2 Demographic Factors

3.2.1 Population

The population is a widely studied variable for residential solar deployment. The correlation between population and residential solar deployment is a broad and complex phenomenon that various demographic, socioeconomic, and environmental variables can impact.

Studies have shown a correlation between solar installations and population density or size, which according to some, is associated with higher uptake due to the more significant number of potential consumers (99). Greater adoption rates have been observed in highly populated locations possible because metropolitan areas, are inclined to have individuals with better financial standings and greater potential for peer effect. Whereas few indicate the opposite suggesting the negative influence of population density on the uptake (91).

Nonetheless, the demographic features of a region's population may also have a significant influence. For instance, age, sex-ratio, and marital status might have a substantial effect on solar adoption rates. Where studies show variable correlation between individual's age and residential solar uptake some illustrates negative association of solar uptake and average age of the individuals (69). Suggesting communities with older individuals have lower solar adoption rates, which may be attributable to their reduced payback periods because of their shorter lifespans. Supported by another study indicating younger householders are more likely to adopt residential solar, probably because they expect to remain in their current residences for an extended period, and hence long-term earnings from their investment (25). In contrast, middle-aged inhabitants appear more inclined to adopt renewable energy for their households than other age groups (94).

A few studies, however, have examined sex-ratio association with residential solar diffusion one of which signifies higher solar adoption rate correlated with greater female proportion (114). Whereas, others demonstrate no association between the two (94, 115). Similarly, no significant relationship between marital status and residential solar adoption has been indicated by any study, yet the variable has not been studied extensively.

3.2.2 Citizenship Status

While these factors are not directly correlated, they interact to either facilitate or impede solar adoption among various ethnic and citizenship groups. Certain socioeconomic challenges, such as less disposable income or house ownership issues, might be associated with particular ethnic minorities, reducing their potential to implement solar technology. Diverse groups exhibit varying knowledge and perspectives towards residential solar, indicating the importance of cultural factors (100).

3.2.3 Area

The diffusion of residential solar might also be indirectly affected by a region's or postcode's area size. Given that, more diversified housing markets with a mix of urban, suburban, and rural residences with different residential uptake patterns could be seen in bigger areas.

In addition, households often have larger roof spaces in places with large typical areas per property, such as rural or suburban areas. Detached or semi-detached dwellings with spacious roof space needed for solar PV installation are these localities' most common housing types. As a result, regions with more significant-sized dwellings may have a greater adoption rate for solar PV.

On the other hand, in areas with a smaller average land size per property, such as urban regions with apartment buildings and smaller residences, the available roof space for residential solar installations is mostly constrained. This limitation might attribute to the decline in adoption of solar PV in such regions.

However, in some studies the region's area is analysed to determine the peer effect influence on the residential solar diffusion because some heavily populated areas have more households with residential solar. In contrast, other overpopulated regions have less, suggesting imitation behaviour or peer effect might be the possible reason for this difference (91).

3.3 Social Factors

3.3.1 Family

Family and household features, the number of families in a dwelling, and the household or family size might significantly impact residential solar adoption. Larger families could find solar PV especially more appealing because of the possible higher electricity consumption for potentially more use of electrical appliances and a larger area to heat or cool. Likewise, houses with several families may consume more energy overall, making residential solar potentially more economical for these households. According to a study in northern parts of Italy, where a smaller number of families living in the same household with higher income levels has a higher number of installations, whereas, in the southern parts with a lower income is observed in a household with a more number of families have lower solar uptake (116). Moreover, another study implicating that a greater number of families in a household in less congested areas tend less to deploy residential solar similar is the case for larger families (102). However, another study suggests an increase in residential solar adoption with an increase in the share of households with larger families in a region (81, 117).

3.3.2 Education

Education level has demonstrated its association with residential solar PV diffusion in various studies. It has been a general perception that higher levels of education correlate with greater solar PV adoption. Those with a higher level of education frequently have a deeper comprehension of the environmental benefits of clean energy sources, such as residential solar. Despite the initial costs, these individuals may also be more likely to recognise the long-term economic benefits of solar adoption. In addition, there is a correlation between education and income, which inevitably plays a significant role in a homeowner's ability to invest in residential solar. Therefore, the level of education of a region's population is one of the key factors to account for while analysing residential solar diffusion behaviour. As suggested by numerous studies around the globe investigating the factors influencing the spatial distribution of solar PV supports the first imply that higher education has been a motivating factor in increasing the solar adoption rate (102, 118, 119). However, a survey-based study examining the effect of incentives on solar adoption aimed at pre-existing theories of their association with uptake suggested previously people with better educated had higher odds to uptake solar PV whereas, currently, the association seems to diminish (120).

3.3.3 Dwellings

Analysts and researchers have commonly accessed characteristics of a dwelling including the type of dwelling structure, the number of bedrooms, and the dwelling age while evaluating the potential for residential solar adoption. Each of these factors has specific effects that determine the probability of the uptake based on its significance and suitability to the residence.

A dwelling's structural features may directly impact the suitability the uptake of residential solar as it encompasses separate house, duplexes, and units/apartment complexes and each of this type exhibits distinct opportunities and limitations for the uptake. For instance, separate houses and duplexes unlike apartments or units who have shared ownership of the property and lacks roof space, have greater likelihood of installing residential solar (14, 102, 119).

Typically, the number of bedrooms in a dwelling is associated with the size of the dwelling and, subsequently, the quantity of energy consumed. Larger dwellings often have higher energy bills, stimulating the rooftop solar uptake among these households to save their energy costs (81, 82). Also, these dwellings are more likely to have larger roof spaces facilitating the installation (121). The age of a home also plays a significant influence. They might need major repairs and renovation for solar installations as the structure of the older roofs may be a concern, thereby increasing the initial cost of solar installations. In contrast, newer homes are typically built to facilitate residential solar adoption and prioritise energy efficiency. Consequently, the uptake is more feasible for these residents (82, 98).

3.3.4 Neighbours

Researchers have extensively studied the impact of peer effect on residential solar diffusion, while a few consider the geographical proximity of the neighbours as a proxy of imitation behaviour. The average distance between neighbours appear to evaluate the likelihood of peer influence or social diffusion within a designated geographic range (97).

Studies illustrate that residential solar diffusion is more affected by the overall adoption trend within an individual's immediate geographic area than by strong personal relationships. Regions where a significant proportion of households in a community uptake residential solar may impact the perspectives of other individuals, motivating them to adopt residential solar (92, 122). The visibility of installed residential solar in the community probably plays a principal role in this behaviour (91). Another study indicated that this effect is more pronounced at the postcode level than higher spatial scale (123).

Table 2. This table describes the main categories of socioeconomic and demographic variables, their respective sub-variables, their definitions used in the literature and references.

Category	Factor	Variable	Definition	References
Demographic	Population	Rural	No of people in rural areas.	(99), (82, 116)

		Urban	No of people in urban area.	(102),(82, 116, 118, 124)
		Postcode	No. of people in a postcode	(81, 84)
		Density	The ratio of total postcode population of a postcode and the total area of the postcode.	(102),(25, 69, 84, 96, 99, 118)
		Sex-ratio	Proportion of Male population and Female population in a postcode	(94, 114)
		Marital Status	Relationship status	(94, 95)
		Age	The median age of a postcode's population.	(14, 25, 69, 81, 82, 84, 94, 96-98, 102, 114, 116-118, 121)
	Citizenship Status	Ethnicity	The proportion of native citizens.	(100),(97, 98, 118)
		Aboriginal	The proportion of Aboriginal and/or Torres Strait Islanders in a Australian postcode.	(14, 100)
	Area	Land Size	Area of a postcode in square kilometres.	(91, 93, 96)
Social	Family	Household	The number of households where a private residence is occupied by one or more dividual among whom at minimum one of the residents age 15 years is called a household.	(102), (124)
		Household Size	Number of people living in a private residence on average.	(69, 98, 102, 116, 117, 121)
		Families	The number of families. According to ABS, more than one person associated with de facto relationship, marriage, step/foster adoption or blood among them, one at a minimum must be of age 15.	(81, 96, 98, 117)

	Education	No education	The percentage of people who have attended less than 8 years of formal education.	(69, 96)
		Primary School	Proportion of people with minimum 7 years of formal education.	(69, 114, 120)
		High School	Proportion of people with least 12 years of formal education.	(14, 69, 114, 116, 118, 120)
		University/ Tertiary	Proportion of people with university level education. Or qualification beyond high school.	(14, 25, 69, 81, 84, 94-96, 98, 102, 114, 116, 118, 120)
	Dwellings	Houses	The proportion of homes among all dwellings. A house is characterised as a residence whose grounds are separated from one another by a minimum of half a metre.	(14, 69, 81, 84, 102)
		Units/ Apartments	The proportion of Units/Apartments among total dwellings. A residential unit or apartment is characterised as a living space that does not possess exclusive outdoor areas and typically shares a communal corridor or staircase. This category encompasses flats, units, and apartments.	(14, 69, 81, 82, 84, 102, 118, 121, 124)
		Duplexes	The ratio of total dwellings that are duplexes. A duplex is a domicile consisting of two dwellings that share a central wall, which include semi-detached dwellings, terrace houses, and townhouses.	(14, 81, 82, 84, 102, 118, 121, 124)
		Bedrooms	The number of bedrooms in a dwelling.	(14, 69, 81, 82, 84, 95, 98, 121)

		Age of house	Age of the dwelling or time length of occupants in that dwelling.	(14, 69, 81, 82, 95, 96, 98, 121)
		Average neighbours 0.5-1 mile	Average no of people living within 0.5-1mile radius.	(82, 96-98, 121)
	Neighbours	Average neighbours 1-4 miles	Average no of people living within 1-4mile radius.	(97)
		Peer Effect	The adoption decision for solar panel influenced by the uptake of members within a peer group.	(25, 84, 91-94, 97, 99, 122, 123, 125, 126)
		Household Income	The median weekly household income of the postcode.	(14, 25, 80-82, 84, 91-97, 99, 102, 104, 116-118, 120-129)
Economic	Income	Personal Income	Average weekly personal income of the postcode.	(14, 80-82, 84, 94-97, 99, 102, 104, 116-118, 120, 121, 124, 127-129)
		Family Income	Median weekly family income of the postcode.	(94, 96, 99, 114)
		Rent	Weekly rent of a dwelling.	(81, 96, 114)
		Mortgage	The weekly repayments of purchasing a dwelling.	(81, 82, 98)
	Housing Ownership	Renter	The number of people who rent dwellings.	(81, 82, 97, 98)
		Private Owner	Number of owner-occupied dwellings.	(14, 81, 82, 94, 96-99, 117)
		Employed	Percentage of employed people in the area.	(14, 81, 94, 96, 98, 99, 116, 117)

	Earnings	Unemployed	Percentage of unemployed people in the area.	(14, 96, 97, 116)
		System Cost	Installation and maintenance costs of the solar system.	(14, 21, 68, 94, 96, 97, 112, 127, 129-132)
	Cost	Electricity Cost	Average electricity cost per house.	(14, 21, 25, 68, 94, 97, 112, 118, 127, 129-134)
	Electricity	Electricity demand	Electricity demand per household.	(14, 25, 68, 94, 97, 102, 118, 132-134)
		Energy Policy	Solar energy policies effecting the uptake of solar system	(65, 80, 102, 135, 136)
Policy	Energy	Feed-in-Tariffs	A Feed-in Tariffs (FiTs) is a payment for electricity fed into the supply grid from a renewable energy source, such as wind or solar panels	(4, 7)(14, 17, 21, 26, 65, 68, 80, 84, 117, 120, 128-131, 133-141)
	Financial Incentives	Tax Credits	Tax deduction due to solar installation	(5)(25, 68, 94, 132, 133)
		Subsidy	The rebate subsidises the installation cost of a solar energy system.	(5)(25, 65, 80, 82, 104, 118, 120, 127, 129, 132, 133, 139, 140)
		Environment	Renewable energy effect on environment	(142-144)
Environment	Renewable Energy and Environment	Solar Irradiation	Solar irradiance is the electromagnetic radiation borne by the earth through sunlight. The SI unit for solar irradiation is Watt per square meter.	(25, 82, 98, 99, 102, 117, 118, 127, 130, 140, 142-147)

	Topography	Finance and Businesses	COVID-19 effect on financial market.	(25, 42, 47, 51-54, 82, 98, 99, 102, 117, 118, 127, 130, 140, 145-151)
Pandemic	COVID-19 Impact	Renewable Energy Businesses	Renewable Energy Businesses potential risks and future	(42, 46, 47, 51-54, 148-151)
		Lockdown	Effect on solar business and installation due to lockdown restrictions.	(46, 149, 150)
		Transport	COVID-19 effect on transporting solar energy related supplies.	(44, 149, 150)
		Environment	Environmental impact of COVID-19 and their relationship with solar energy.	(44, 45, 49-51, 65, 133, 150, 152)

3.4 Economic Factors:

The adoption of solar energy is significantly influenced by the economic factors of individuals. The decision-making process of individuals regarding investment in solar energy systems is influenced by various economic aspects. Several studies suggest that many economic variables are correlated with each other and sometimes it is not trivial to analyse the individual set of variables without considering other variables. Some of the major economic factors which have found to be affecting the solar energy market, are mentioned in following paragraphs.

3.4.1 Income:

The level of income is considered a critical factor in solar energy adoption in a society and the correlation between income level and the adoption of solar energy is a critical factor to consider. Individuals with higher income tend to possess greater disposable income which can be allocated towards investment in clean energy technologies. The economic feasibility of solar PV systems, encompassing both initial installation expenses and long-term maintenance costs, is a critical factor in the determination of whether to embrace solar energy. According to a study conducted in Italy, household income is a significant determinant of economic conditions in various regions, and it is influenced by multiple socioeconomic factors such as the household type and monthly income (116). Another study was conducted to investigate the impact of financial assistances, incentives and household incomes on individuals' behaviour and preferences to uptake rooftop solar PV. The research findings indicate that there is a plausible positive moderation effect of household income on the relationship between consumer perspective on technology and motivation to buy it. Additionally, it was observed that these financial assistances and benefits positively influence the interaction effect of household income. The findings suggest that an increase in family income and greater awareness of subsidy incentives may facilitate the conversion of pro-environmental attitudes into a willingness to purchase eco-friendly equipment. (114).

3.4.2 Housing Ownership:

The ownership status of housing has been found to have a notable impact on the adoption of solar energy systems. It is commonly observed that homeowners possess the autonomy to make determinations regarding alterations and capital outlays on their respective properties. The research findings indicate that individuals possess the capacity to install solar panels on their rooftops without necessitating authorisation from landlords or property management. Consequently, the adoption of solar energy systems by homeowners is facilitated by the increased level of control they possess over the decision-making process, thereby streamlining the installation process. The findings of a study conducted in Australia indicate that house ownership is a significant socio-economic factor in residential solar diffusion. The findings of the analysis corroborate earlier research indicating that home ownership is a significant factor in explaining the residential solar adoption behaviour. Furthermore, the data suggest that the dwelling most likely to have a solar PV installation is a single-family dwelling with a minimum of three bedrooms and more than two residents. Furthermore, the analyses suggest that individuals who are 55 years of age or older and reside in rental units are at a higher risk of being excluded from the adoption of solar photovoltaic technology. Individuals aged 55 years and above who are renting may be considered the most susceptible to the impacts of rising electricity costs, particularly with regard to equity considerations (81).

3.4.3 Employment Status:

Similarly, an individual's work situation has the potential to affect their choice to utilise solar energy in a variety of different ways. There are several key factors to take into consideration, including the financial viability of solar energy systems and their return on investment (ROI). People who are currently employed may have a greater ability to analyse the possible cost savings and return on investment in terms of energy over time. It is crucial to note that although work status can play a role in determining whether an individual chooses to adopt solar energy, doing so is not limited to people who are currently in paid employment. According to the findings of a study that was carried out in Germany, there appears to be a considerable connection between a region's socioeconomic position and the pace at which it adopts PV technology. Specifically, the findings suggest that higher population percentages of people who have high incomes and high levels of education, in addition a decrease in unemployment rates is associated with an increase in residential solar uptake (96) .

3.4.4 Cost of Solar System:

The financial implications of implementing a solar energy system are a pivotal consideration that shapes the determination to embrace solar power. The economic viability and desirability of adopting solar energy are assessed based on several factors, including affordability, financing alternatives, payback duration, accessible incentives, and long-term cost-effectiveness. The declining cost of solar systems and the increasing availability of incentives are contributing factors to the growing appeal of solar energy adoption among individuals. According to a study, the investment in solar PV requires a net present value of benefits that is nearly twice the amount of the initial investment cost in order for the investment to be deemed feasible (132).

3.5 Energy Policy and Financial Incentives

The solar energy market is notably influenced by energy policies and financial incentives, including but not limited to Feed-in-Tariffs, Tax Credits, and Subsidies. The provision of incentives is of paramount importance in facilitating the acceptance and expansion of solar energy systems, as it renders them more appealing to both individual and corporate consumers from a financial standpoint. The subsequent paragraphs underscore the significance of financial incentives and their relevance in prior research.

3.5.1 Feed-in Tariffs:

Feed-in-Tariffs (FiTs) refers to the incentive schemes that remunerate electricity producers, particularly those who own solar energy systems, at a higher rate for the electricity generated and supplied to the grid. FiTs offer a stable and consistent source of income over an extended period, thereby enhancing the attractiveness and financial feasibility of investments in solar energy. FiT incentivize the installation of solar energy systems and promote market expansion by ensuring a financial beneficial return on investment. A research investigation carried out in the United Kingdom has established that the implementation of the FiT has expeditiously amplified the implementation of photovoltaic (PV) technologies at a small scale after its inception in April of 2010. The primary tenet of FiT policies is to provide assured pricing for predetermined durations, thereby facilitating increased participation from investors (130). Moreover, a recent study conducted on the Japanese solar energy market has revealed that the implementation of the FiT programme is anticipated to result in a noteworthy surge in the quantity of residential solar installations, particularly within the commercial sector. The financial analysis indicates that non-residential installations in Japan, with an installation size of 100 kW, could potentially yield an annual ROI of 7.43% (131). Nevertheless, certain studies contend that FiT exhibit a consistent positive correlation with the expansion of the solar market, while also potentially displaying negative tendencies. Another investigation conducted on European nations utilising FiT has identified the circumstances that may lead to the failure of a FiT system. The combination of low levies, high FiT rates, and a significant adoption of clean energy resources are the aspects that contributed to the failure of the FiT programmes. The collapse of the FiT scheme in Cyprus and Spain can be attributed to the point at which the level of renewable production exceeded a threshold, resulting in a nett cost being imposed on the system. Consequently, countries that implement FiT programmes must reassess their tariff payment rates for photovoltaic (PV) systems to facilitate a more moderate integration of PVs into the power grid, while maintaining the coherence of the current scheme. (134).

3.5.2 Tax Credits:

Tax Credits are a viable financial incentive that mitigates the overall expenses associated with the installation of solar PV systems. Tax credits are available for individuals and businesses who invest in solar equipment or installations, allowing them to claim a percentage of their investment as a credit against their tax liability. Tax credits serve to decrease the initial expenses associated with solar installations, rendering them more economically feasible and expediting their implementation. The subject of tax incentives design requires a significant attention as they possess the attribute of flexibility, which enables them to be directed towards a particular technologies and categories of investors. It is possible to strengthen them during the initial phases of clean energy sector development and subsequently eliminate them as the domestic clean energy sector progresses and attains independence. The achievement of desired outcomes may be influenced by intricate interplays with additional governmental reforms and macroeconomic factors, which can speed up or slow down growth.

According to a prominent study, renewable energy generation encounters a tax disadvantage owing to its capital-intensive character in contrast to conventional power generation, as numerous taxes are predicated on financial investments. In order to address this drawback, it is possible to introduce tax incentives. It is recommended that a comprehensive policy package be implemented to facilitate the expansion of the renewable energy industry, which should include the integration of these incentives. Gradual adjustments to the composition of tax incentives for renewable energy should be made over time to ensure alignment with the industry's developmental stage. It is recommended that a systematic timetable be implemented to gradually eliminate specific incentives as the local businesses expands and the industry reaches a state of maturity. Furthermore, it is also possible for the countries to derive the advantages by adjusting their array of tax incentives in order to more effectively correspond with the level of advancement of their renewable energy sector (41).

3.5.3 Subsidies:

Subsidies refer to monetary inducements extended by governmental bodies or utility corporations to mitigate the expenses incurred in the installation of solar energy systems. Diverse modalities of subsidies can be implemented, including but not limited to cash incentives, grants, or rebates. Subsidies have the potential to enhance the accessibility of solar energy and promote its widespread adoption by reducing the initial investment cost. According to a study conducted on the Japanese solar market, it has been found that the regional subsidy policy has a noteworthy positive effect on the installation of photovoltaic (PV) systems (127). In this study, it is asserted that government subsidy programmes are apparently of utmost importance and that cost reduction in conjunction with ongoing government and other assistance systems has considerably promoted the dissemination of PV systems. Cost reductions, ongoing government backing, and other assistance programmes can all be credited for the significant development in PV system adoption. It is obvious that government subsidy programmes have a major impact on this development. It is suggested that the deployment of improved long-term subsidy schemes and regional promotion policies bears enormous relevance in supporting further diffusion of PV systems, even though addressing cost reduction problems remains necessary for future expansion. Collectively, the solar energy market experiences a favourable impact from the cumulative effect of various financial incentives. Solar energy system manufacturers, installers, and consumers are encouraged by the creation of a favourable business environment, which stimulates demand and incentivizes investment. Financial incentives exhibit the capacity to accelerate the uptake of renewable energy sources, mitigate the effects of climate change, and foster sustainable development by decreasing the payback period and enhancing the return on investment.

3.6 Environment:

3.6.1 Renewable Energy and Environment

The correlation between the utilisation of renewable energy sources and their ecological ramifications constitutes a pivotal facet of the shift towards sustainable energy frameworks. In order to shift from traditional energy resources that rely on fossil fuels to sustainable energy resources such as solar, wind, hydro, and geothermal has numerous beneficial impacts on the environment. One of the primary advantages is the substantial decrease in emissions of glasshouse gases. Renewable energy technologies have the capacity to significantly cut off carbon and other harmful emissions during generating electricity process, thus effectively mitigating their impact on climate change. Renewable energy sources have the potential to mitigate air pollution by replacing the combustion of fossil fuels, thereby enhancing air quality, and promoting human health. In the context of solar energy as a feasible renewable energy source, various research initiatives have been conducted to illustrate the benefits of utilising sustainable energy sources in terms of their ecological impact. As per a reputable research, solar energy exhibits minimal health and environmental impacts in contrast to fossil fuels. The research suggests that with the increase in gas prices, solar energy will emerge as a more appealing and viable energy alternative (142-144) .

3.6.2 Topography of Region:

The topological effect is crucial to producing solar energy and cannot be ignored. A solar power system's topology or structural composition and design directly impact its efficiency and effectiveness. Solar panels must be constructed and oriented correctly to maximise energy output and installed considering any shading structures or other barriers. The topological effect account for elements that affect how much sunshine the solar panels get, including shading patterns, tilt angle, and azimuth angle. Solar panels are installed effectively to receive the greatest amount of sunlight possible throughout the day in a well-designed topology, improving energy output. Moreover, planning the topology accounts for cable routeing, panel connections, and the system's overall effectiveness. Solar energy systems may be made to function better overall and with greater energy production by optimising for the topological impact. In order to take advantage of the topological effect and maximise the potential for electricity generation from solar panels, extensive planning, appropriate design, and correct installation of solar energy systems are crucial.

Significant technological advances have been made in tracking solar irradiance in various regions of the world, which determines the optimal starting point for solar systems installation to achieve their optimum efficiency. (37). According to an Australian study, satellite radiation approximations are initially created and corrected afterwards to enhance the precision of the Australian solar irradiance map. Moreover, this study verifies the world's standard and tilted satellite radiation through ground measurement, ensuring a precise technique to evaluate the optimal location in Australia for solar panel installation (145). Another algorithmic optimisation study from Europe has developed a free online service to monitor the quality of global radiation measurements received horizontally between

1983 and 2018 at any point in Europe.(37). Researchers in another study, have used irradiation time series data from 14 measurement sites around Australia to extract cloudless times, which were then compared and ranked against nine global and nine beam clear sky models (146).

3.7 Pandemic Effects on Solar Energy Market:

3.7.1 Impacts on solar energy businesses:

COVID-19 has had a substantial and diverse effect on the financial markets. Overall, the pandemic has created uncertainty in the global economy and has aggravated market volatility. The outbreak of the pandemic led to substantial declines in stock markets, primarily due to concerns about the potential economic deceleration and the ambiguity surrounding the virus's effects (153), (148). New research analysing the effect of COVID-19 on solar PV projects in China, specifically examining the degree of impact and the duration of action. Research indicates that the solar PV sector has experienced a delayed response to the pandemic, with the COVID outbreak-induced shutdown in China lasting approximately one quarter (47). Furthermore, empirical evidence suggests that the pandemic-induced financing and investment costs trend has resulted in a rising burden on the expenses of newly established photovoltaic power initiatives in a short time, with an approximate escalation rate of 3%. (47).

However, another research has found a correlation between the share prices of solar companies and COVID-19 cases and between the severity of the government intervention and those share prices. According to this research, based on the long-term parameters, COVID-19 has decreased the share prices of the majority of solar energy businesses, mainly due to the government's COVID-19 preventive strategy (52).

3.7.2 Lockdown and financial market:

Using a spatial econometrics technique, a study has examined the association between the strength of COVID-19 stringency and the return on investment. The study investigates how different lockdown measures affect stock market performance in various locations and nations. The study demonstrates a negative correlation between the lockdown's stringency level and the stock market's growth, with tougher lockdown restrictions correlated with a decline in return on investments. A thorough investigation of the effects of lockdown restrictions on stock markets is possible because of the spatial econometrics technique, which accounts for the geographical interdependence across areas (149).

3.7.3 Effect on Transport and supply chain:

The transportation sector constitutes a significant element of the energy system, serving as a crucial factor in generating a substantial proportion of glasshouse gas emissions yet essential for everyday life while as a principal element in the supply chain, became clear on a global scale for health and safety equipment and associated devices during the dramatic weeks in early 2020. According to a study, the post-pandemic period might not be viewed as a challenging time for clean energy as some analysts initially claimed, but rather as a period of change that could be taken advantage of as a once-in-a-lifetime opportunity to advance transportation to decarbonization and support the European Union economic development. Thus, the path to sustainable transportation fuels offers a clear chance to achieve post-pandemic social, economic, and climatic change goals through an effective win-win strategy (44).

3.7.4 Effects on earth's environment:

Whenever there is a significant shift in financial activity, the natural environment will be affected. The COVID-19 shockwave and subsequent closure had an evident rapid effect on global glasshouse gas emissions, provided the effects on logistics and mobility. As a consequence, there have been reports of a decline in carbon and nitrogen dioxide emissions, as well as a positive change in environmental conditions, particularly regarding air quality. According to the IEA, worldwide CO2 emissions were nearly 5% less in the first quarter of 2020 than in the first quarter of 2019, mostly as a result of decreases in emissions from oil (down 4.5%), coal (down 8%), and natural gas (down 2.3%). In order to achieve 30.6 Gt during 2020 (8% less than in 2019), the anticipated reduction is predicted to accelerate even faster in the following months (44). Many individuals have adopted staying at home during longer lockdowns as a new norm, which increases energy consumption in houses (such as water and electricity) and influences household waste generation means and characteristics. Additionally, it has a human-induced effect on air, water, and soil systems (45).

Furthermore, a recent study has examined the temporary and lasting environmental impacts of Covid-19 from a broader point of view. Temporarily, the roadways, airspace, factories, and commercial office buildings have deserted the roadways, the skies, manufacturing plants, and trade offices, resulting in GHG emissions reduction and thus a cleaner environment, yet with a tremendous cost to the economy and public health. COVID-19 lasting impacts are extremely unclear; thus, a hypothesis to give a better understanding of its ecological effects is suggested (49). In addition, another research highlights that subsidies must be perceived as favourable climate change sources that curtail emissions levels rather than an enduring form of aid, transforming beneficial environmental effects into economic benefits (133).

3.8 Recent studies of COVID-19 pandemic effect on renewable energy market

The COVID-19 pandemic has significantly affected various socioeconomic factors worldwide. The implementation of measures aimed at mitigating the spread of the virus, including but not limited to lockdowns, travel restrictions, and business closures, have led to extensive economic disruptions. Research has indicated that there are negative impacts on employment, including substantial consequences such as job losses, furloughs, and reductions in income (154). The impact of the current economic situation has been particularly severe on small enterprises and industries that are susceptible to external shocks, resulting in economic difficulties for both individuals and communities (155). Moreover, the pandemic has intensified pre-existing social and economic disparities, whereby disadvantaged communities and individuals with low socioeconomic status have encountered disproportionate repercussions (156). The compromised access to education, healthcare, and social services has exacerbated the socioeconomic challenges confronting numerous individuals. The enduring ramifications of these socioeconomic disturbances are anticipated to have significant implications, necessitating all-encompassing approaches and assistance mechanisms to reconstruct economies, tackle disparity, and promote all-inclusive expansion (157).

Further to COVID-19 pandemic effect on socioeconomic and demographic variables, it has also casted a substantial impact on the energy sector, including the renewable energy sector, due to its global reach. The current pandemic and its associated impacts persist, and a comprehensive examination of the influence of socioeconomic factors on the energy market remains to be established. To date, only a limited number of studies have been conducted on this topic. A recent study investigates the interconnections between rare earths and six principal renewable energy reserves, with a specific emphasis on their co-movements in time-frequency domain, spill-overs of returns, and market fluctuation. The findings indicate that the COVID-19 pandemic has resulted in a notable rise in co-movements and in return-on-investment, spill-overs and market fluctuation among sustainable energy and rare earths market fluctuation and returns on investment. Rare earth elements exhibit a tendency to receive both market fluctuation spill-overs and return on investment, whereas the green energy equities demonstrate a propensity to transmit market fluctuation spill-overs and return on investment prior to and amidst the COVID-19 pandemic. Furthermore, it is argued that Solar and wind stocks exhibit a dual role as transmitters and receivers of spill overs investment prior to and amidst the COVID-19. Furthermore, the remaining markets demonstrate shifts from being recipients to transmitters, or the other way around, highlighting the impact of the COVID-19. The findings suggest that the approaches used for cross-market hedge may experience reduced effectiveness in the times of crises, emphasizing the need for portfolio rebalancing (158).

In addition to the statistical study on the variables, a few studies related to policy developments and implications has also been proposed. An investigation has been done recently which provides a thorough investigation of the effect that the COVID-19 has had on the attainment of two specific sustainable development goals. The assessment also examines the interdependent nature of water and energy accessibility regarding sustainable development, while considering the effects of the COVID-19 on the water-energy nexus. The article also suggests integrated solutions that promote stability in the water supply chain, energy storage, and policymaking during and after outbreaks are crucial for achieving developmental goals (159).

On the contrary, although the decline in energy consumption caused by the epidemic nearly triggered a financial crisis, a research study has foreseen the positive impacts of this pandemic situation. During pandemic, reduced human interference allowed natural systems to re-establish themselves and restore climate stability. As a result of the pandemic, governments and investors around the world have the opportunity to think about reducing their countries' carbon footprints and moving towards a goal of net-zero emissions. Nearly doubling green energy investments creates openings for reviving the economy through the creation of new green energy enterprises and the application of government fiscal policies. While it may be appealing to focus on renewable energy for post-pandemic recovery, experts recommend focusing on limiting economic fallout and helping struggling businesses first. In order to achieve sustainable development, long-term planning and strategies are required (160).

3.9 Conclusions

In summary, extensive research has been conducted on the influence of environmental, socioeconomic, and demographic factors on residential solar diffusion, and the sudden COVID-19-driven changes in these variables still need to be explored. This raises unresolved questions of significant importance. For instance, how did staying home for an extended time due to lockdowns and physical distancing restrictions impact the residential solar diffusion rate? How did supply chain interruptions impact the accessibility and pricing of solar equipment? How does a health crisis-induced change in government policies impact residential solar incentives and subsidies?

Conclusively, the unprecedented circumstances imposed by COVID-19 have exposed unexplored areas in the domain of residential solar uptake. The evolving social, economic, and government policies entail novel research addressing these gaps. This research would not only help to comprehend the changing nature of residential solar uptake behaviour during a crisis. However, it will also facilitate the stakeholders and policymakers to develop more resilient strategies to accelerate the growth of the residential solar market.

Chapter 4: Statistical Models

The chapter discusses various models to provide a comprehensive overview of the most extensively employed models relevant to this study of residential solar uptake, especially considering the influential socioeconomic and demographic variables. While there may indeed be other models available, these particular models have been widely recognized and utilized within the context of this research domain. This section serves to establish a strong foundation for the methodology employed in our study and offers transparency regarding the frameworks and approaches used to analyse the data and draw meaningful conclusions. The chapter concludes by explaining the rationale behind selecting the chosen model for this study in comparison to other models. This clarification helps in highlighting the specific strengths and suitability of the selected model for addressing the research objectives in the context of COVID-19's effect on residential solar uptake. It's essential to establish why a particular model was preferred over others to ensure transparency and rigor in the research process.

4.1 Introduction

Socioeconomic and demographic variables of a society play a fundamental role in adopting a certain technology. Considering the complexity and voluminous nature of socioeconomic and demographic data, it is imperative to possess a rational comprehension of the statistical and mathematical frameworks employed in prior research concerning these variables. The utilisation of statistical and mathematical models necessitates a systematic and precise methodology for scrutinising the variables and their interrelationships. By means of these models, one can discern the paramount variables that exert influence upon the solar energy market and gauge their respective magnitudes of impact. In addition, the utilisation of statistical and mathematical models can aid in the identification of potential impediments to the widespread adoption of solar energy, as well as the development of effective strategies to surmount these obstacles. The utilisation of said models can effectively promote a more all-encompassing comprehension of the solar energy market and its fundamental intricacies, a crucial component in the realisation of an enduringly sustainable energy landscape. The comprehension of these variables may facilitate the discernment of suitable models for scrutinising the ramifications of said variables on the solar energy industry in Australia, pre- and post-COVID-19. In essence, the socioeconomic and demographic variables when analysed using a suitable mathematical and statistical technique, possess the potential to furnish policymakers, investors, and other pertinent stakeholders with the necessary knowledge to make judicious determinations regarding the advancement and utilisation of solar energy technologies. For aforementioned reason, a simplified version of these models is their significance in previous studies on solar energy market is briefly described in the following paragraphs.

4.2 Linear Regression Model

The Linear Regression Model is a statistical technique frequently utilised to model the correlation between dependent and independent variables. The fundamental assumption is based on the concept of a linear relationship between the dependent and independent variables. The model can be written as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_p X_p + \varepsilon$$

where 'Y' denotes the dependent variable, 'β_0' to 'β_p' symbolise the coefficients to be estimated, 'X_1' to 'X_p' represent the independent variables and 'ε' symbolises the error term.

The objective of the linear regression is to provide approximation of the coefficients that best fit the data, using the least squares fitting method, a technique that minimizes the sum of the squares of the differences between the measured and the predicted values of the dependent variable (161). This implies that the optimal line of regression is the one that minimises the Euclidean distance between the observed data points and the line.

Linear regression is a frequently employed statistical method for illustrating the relationship between a dependent and one or multiple independent variables. Nevertheless, it is important to consider the various constraints of this model. The initial assumption posits a linear correlation between the independent and dependent variables, which may not consistently hold true in practical applications (162). Secondly, it assumes zero multicollinearity among the independent variables, which can produce biased estimates and incorrect conclusions (163). Thirdly, it considers that the errors or residuals are normally distributed, which may not always be correct in practice. (164). Fourthly, it also supposes that there is no heteroscedasticity or non-constant variance of the errors across the range of the dependent variable, which can lead to incorrect inferences and confidence intervals. Finally, the linear regression model supposes the independence and normal distribution of the data, which may not be universally applicable in practical scenarios (165).

Although it has certain constraints, linear regression has been widely employed to explore the effect of socioeconomic and demographic features on the uptake and spread of solar energy in different geographical areas worldwide. Numerous studies have explored the correlation between said variables and the implementation of solar energy in the United States, European countries and Australia as well. These studies offer significant knowledge for policymakers and researchers investigating the interplay of socioeconomic factors, demographics, governmental policies, peer behavior, and electric prices in the diffusion of solar PV (166), (167), (168), (169), (170), (171), (172).

4.3 Logit Model

In statistics, the logit model, also known as the logistic model, is a generally employed statistical model to analyse and predict binary outcomes. This model estimates the probability of the binary event which will appear depending upon one or more independent variables. It converts the probability into the log-odds (logarithm of the odds), which represents a linear relationship with the independent variables. Generally, the logit model can be written in equation form as: -

$$\text{Logit}(p_i) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \ldots + \beta_p X_{p,i}$$

In this model equation, 'Logit(p_i)' denotes the log-odds of the event occurring with a probability 'p_i', '$X_{1,I}$' to '$X_{p,i}$' are descriptive variables, and 'β_0' to 'β_p' are the coefficients to be estimated (173).

Despite its extensive usage, this model is associated with various limitations. The Logit model is predicated on linear correlation between the independent variables and the logarithm of the odds of the dependent variable assumption where odds refer to the ratio of the probability of an event happening to the probability of the event not happening. However, this assumption may not always be applicable in real-world situations (174). Secondly, the model assumes that the errors exhibit independence and identical distribution, which may not be valid if there exists correlation among the observations or if the data is clustered (175). Thirdly, the model assumes the absence of multicollinearity among the independent variables, which may result in unstable and biased estimates. In the fourth instance, the model postulates that the functional configuration of the correlation between the independent variable and/or multiple dependent variables are accurately delineated, which may not invariably hold true in practical scenarios (176). Lastly, the Logit model is susceptible to outliers and dominant observations, which can alter the results and affect the rationality of the model (177).

Despite its limitations, the logit model has been deemed useful in examining the influence of socioeconomic and demographic factors on the uptake and spread of solar energy in different nations such as with studies using household or individual-level data. The theoretical framework incorporates the sociocultural dimensions of innovation adoption, including values, norms, and beliefs, alongside the economic and technological determinants that shape the adoption of innovation (178), (179), (180), (181).

4.4 Probit Model

The Probit Model is another binary regression model that is like the Logit Model but uses a different functional form. The model is a statistical method utilised for regression analysis in cases where the dependent variable possesses binary or dichotomous nature. This model estimates the likelihood of an event, such as the adoption of a novel technology, by utilising a series of uncorrelated variables. In the Probit Model, the probability of compliance is modelled using the cumulative normal distribution function. Mathematically, the Probit model is described using maximum likelihood estimation, and takes the form:

$$P(Y=1|X) = \Phi(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_p X_p)$$

Where '$P(Y=1|X)$' represent the probability of a certain condition 'Y,' 'Φ' denotes the function of cumulative normal distribution, while symbols 'Y', 'X_1' to 'X_p' and 'β_0' to 'β_p' are as defined as in the Logit Model (182).

The Probit model is a prevalent method for analysing binary and categorical outcomes, but it has some constraints. One limitation is that it assumes linearity between the independent variables and the probability function of the dependent variable, which may not always be precise (165). Another limitation is that it pretends the errors are normally distributed, which may not be the case in some applications (176). Moreover, the probit regression model postulates that the marginal effects of the predictor variables remain constant throughout the spectrum of the response variable, a condition that may not be satisfied (175, 183). Furthermore, the explication of the coefficients in the probit regression model can pose difficulties, as they are expressed in the form of the standard deviation of the residuals rather than the units of the response variable (183). Finally, the probit model may provide inaccurate results from multicollinearity, which can govern large uncertainty in the estimates (174) .

Nevertheless, the Probit model has been utilised to investigate the impact of socioeconomic and demographic features on the acceptance and spread of solar energy in different regions (184), (185).

4.5 Structural Equation Modelling (SEM)

Structural equation modelling (SEM) is an arithmetic technique often harnessed to model the interactions between latent and observed variables. The technique implies detailing multiple linear equations that connect the latent variables to the observed variables, and then approximating the parameters of these equations using maximum likelihood method. The basic SEM model can be illustrated by the following set of equations:

$$y = Bx + e; x = Gz + u$$

where ‘y’ denotes the vector of observed variables, ‘x’ shows the vector of latent variables, ‘B’ represents a matrix of regression coefficients describing the relationship between observed and latent variables, ‘e’ symbolises a vector of random errors in the observed variables, ‘z’ describes a vector of exogenous variables that influence the latent variables, ‘G’ signifies a matrix of regression coefficients that describe correlation between the exogenous variables and latent variables, and ‘u’ stands for a vector of random errors in the latent variables (186). The model can be expanded to incorporate multiple latent variables, multiple observed variables, and multiple exogenous variables. Besides, the model can be exploited to test hypotheses relate the latent and observed variables, and the exogenous and latent variables (187).

SEM has several restraints. One of the major constraints of SEM is that it requires a large data set to estimate the results (174). Another limitation is the assumption of data being normally distributed, which may not always be the case in practice (175). Additionally, SEM entails the linear relationships between the variables, and may not acquire non-linear relationships between the variables (176). Another limitation of SEM is that it is susceptible to the characteristic of the measurement mechanisms used to collect the data (183).

In spite of the limitations, various studies have used SEM to study the factors that stimulate the adoption and diffusion of solar energy (188). A research investigation carried out in South Korea employed SEM to analyse the influence of several factors on the inclination to embrace solar photovoltaic (PV) systems among inhabitants residing in apartment buildings. The findings indicate that variables such as environmental concern, perceived behavioural control and subjective norms cast a substantial effect on the likelihood of individuals intending to adopt solar photovoltaic (PV) systems (188), (189), (190), (191).

4.6 Spatial Econometric Panel Models

Spatial Econometric Panel Models (SEPMs) are a class of regression models employed to investigate the relationship between spatially dependent variables over time. The models incorporate both spatial and temporal autocorrelation, and take the form:

$$Y_{it}=\rho W_i Y_{it} + X_{it}\beta + \alpha_i + \varepsilon_{it}$$

where ‘Y_{it}’ denotes the dependent variable for the ith observation at given time ‘t’, ‘X_{it}’ describes the vector of explanatory variables for the ith observation at specific time, ‘W_i’ represents a matrix of spatial weights, ‘ρ’ represents the spatial autocorrelation coefficient, ‘β’ is a vector of coefficients associated with the independent variables, α_i is the individual-specific fixed effect. The model also incorporates an error term ‘ε_{it}’, which is supposed to have temporal and spatial autocorrelation(192).

SEPMs are extensively utilised in the domain of econometrics; nevertheless, they are not devoid of their constraints. A significant constraint associated with SEPMs pertains to the problem of model specification. The intricate spatial interdependence present in panel data poses a challenge in accurately determining the appropriate model structure. Selecting an inappropriate model specification may result in partiality and incoherence in estimations (193). Another limitation of SEPMs is the inference of stationarity, which is needed for panel data analysis. Nonetheless, spatial dependence is often non-stationary and progresses over time, interrupting this assumption. Consequently, traditional SEPMs may not accurately apprehend the change of spatial dependence over time (194). Additionally, SEPMs need a large amount of data to assess their factors precisely, especially when dealing with large spatial divisions such as countries or regions. This can lead to computational challenges, specifically with respect to approximation and inference (195). Lastly, SEPMs assume that spatial dependence is exogenous, which means that it is not altered by any excluded variables in the model. However spatial dependence may be endogenous, meaning that it is persuaded by other factors that are not incorporated in the model. Failure to constitute endogenous spatial dependence can lead to biased estimates and inaccurate inference (196).

However, SEPMs have been extensively utilised to assess the influence of socioeconomic and demographic factors on the solar energy industry. These models incorporate the spatial autocorrelation among regions and the temporal dynamics of panel data. SEPMs, or spatial econometric panel models, are a valuable tool for analysing the spatial and temporal impacts of various factors that affect the adoption and diffusion of solar energy (197), (198), (199).

4.7 Decision Tree Model

The decision tree model is a commonly employed machine learning algorithm that facilitates prediction and classification of objects by utilising a predetermined set of input features. The decision tree model shapes input features in a hierarchical or categorized formation resembling a tree in which internal nodes denotes tests on input features and leaf nodes describe the class labels or predicted outcomes. Decision tree models are a frequently utilised tool in research that seeks to investigate the associations among numerous predictor variables and a solitary outcome variable. These models possess multiple benefits that render them highly valuable for examining the variables that impact the acceptance of solar energy technologies. The decision tree model is a popular data mining method that can handle categorical and continuous data. The identification of correlation between a dependent variable and multiple independent variables is a valuable application.

The decision tree model is a popular machine learning algorithm owing to its straightforward and comprehensible framework. Nevertheless, it is imperative to consider various constraints of this model. Decision trees have a limitation in that they tend to overfit training datasets that, results in suboptimal functioning on a novel, unobserved data (200). Another limitation is their failure to describe complex relationships between variables, specifically those that are non-linear or encompass interactions between variables (201). Decision trees can also be vulnerable to small variations in the data and may yield different trees for similar datasets (202). Furthermore, decision trees can strain with excessive data, where one class of the target variable is much less common than the others, leading to subjective predictions. Lastly, decision trees are known to be biased towards choosing variables with more levels or categories (203).

Despite the limitations, decision tree models have been widely used in numerous studies to explore the impact of socioeconomic and demographic variables on the solar energy market (204), (205), (206), (207), (208), (209), (210).

4.8 Time Series Model

Another frequently employed model called the time series model is employed to analyse the data that exhibits temporal variability. It is a set of mathematical equations that illustrate the correlation between past observations and forthcoming time series values. The simplified time series model predicts the future value of a series as a linear combination of its past values. The simplified equation can be written as:

$$Y(t) = c + \varphi_1 Y(t-1) + \varphi_2 Y(t-2) + ... + \varphi_p Y(t-p) + \varepsilon(t)$$

where Y(t) denotes the series value at a given time ‘t’, ‘φ_1’ to ‘φ_p’ denotes the coefficients of autoregressive, ‘c’ represents a constant, ‘ε(t)’ symbolises the error term, and ‘p’ describes the order of the model.

Another commonly used time series model is primarily called the moving average model (MA), which estimates the future value of a series as a linear combination of its past errors. The model equation can be expressed as:

$$Y(t) = c + \varepsilon(t) + \theta_1 \varepsilon(t-1) + \theta_2 \varepsilon(t-2) + ... + \theta_q \varepsilon(t-q)$$

Given that ‘Y(t)’ represents the time series value at a given time ‘t’, while ‘c’ denotes a constant. Additionally, ‘ε(t)’ signifies the error term at time ‘t’, and ‘θ_1’, ‘θ_2’, …, ‘θ_q’ denote the moving average coefficients. It is important to note that q represents the order of the MA model.

Another type of time series model, generally termed as the autoregressive moving average model (ARMA), is combination of the AR and MA models, and is represented by:

$$Y(t) = c + \varphi_1 Y(t-1) + \varphi_2 Y(t-2) + ... + \varphi_p Y(t-p) + \varepsilon(t) + \theta_1 \varepsilon(t-1) + \theta_2 \varepsilon(t-2) + ... + \theta_q \varepsilon(t-q)$$

In this equation, ‘Y(t)’ denotes the series value at a given time ‘t’. The model includes moving average coefficients ‘θ_1’ to ‘θ_q’ and autoregressive coefficients ‘φ_1’ to ‘φ_p’. The error term at time ‘t’ is represented by ‘ε(t)’, and ‘c’ is a constant. The orders of the AR and MA components are denoted by ‘p’ and ‘q’, respectively. Apart from the aforementioned models, there exist various other time series models including the autoregressive integrated moving average (ARIMA) model, seasonal ARIMA (SARIMA) model, and exponential smoothing models (211, 212).

Time series models possess significant capabilities in examining data that changes over time. However, they also have a few limitations that needs to be considered critically. The characteristics of normal distribution and independence of the data points are the key assumption of time series models. This indicates that the probability distribution of the data remains constant across time and there is no correlation between adjacent observations. However, this assumption can be limiting in certain scenarios. This assumption may not hold true in many real-world scenarios, leading to biased or inefficient parameter estimates (212). Additionally, time series models are susceptible to outliers, missing data, and model specification errors, which can impact forecast accuracy and result in erroneous inferences (213). A potential drawback of time series models is their potential inability to fully capture the intricacies and non-linearities of the data-generating process, particularly when there are numerous interdependent factors that impact the outcome variable. This can result in a poor fit to the data and inaccurate forecasts, leading to incorrect policy decisions or suboptimal resource allocation (214). Notwithstanding these constraints, time series models persist as a valuable tool for scrutinising and predicting time series data, and their efficacy can be enhanced by utilising suitable data pre-processing, model selection, and diagnostic assessments (215, 216).

Time series models also hold statistical significance in assessing and establishing the influence of socioeconomic and demographic factors on the global solar energy market. Multiple studies have reported significant impacts of these variables on the solar energy market (217), (218), (219), (211).

4.9 Geographically Weighted Regression

Geographically Weighted Regression (GWR) is a statistical technique that develops multiple regression models to investigate spatially varying relationships between variables. In GWR, the relationships between variables are modelled locally, rather than globally. This is accomplished by approximating an isolated regression model at each location within the study area. The GWR model can be represented in mathematical form as follows:

$$Y_i = \beta_0(x_i) + \beta_1(x_i)X_{i1} + ... + \beta_p(x_i)X_{ip} + \varepsilon_i$$

where ‘Y_i’ is the ith observation's dependent variable, ‘X_{i1}’ to ‘X_{ip}’ are the ith observation's independent variables, ‘$0(x_i)$’ to ‘$p(x_i)$’ are the ith observation's coefficients, ‘i’ is the ith observation's error term, and x_i is the ith observation's spatial position. The GWR model's coefficients are computed by a weighted least squares approach, and they vary over space. The weights employed in the estimate process are based on a kernel function that allocates larger weights to data closer to the place being modelled, and lower weights to observations farther away. The kernel function employed in GWR can take numerous forms, such as Gaussian, bi-square, or exponential. The bandwidth of the kernel function determines the spatial extent of the local regression models. A smaller bandwidth leads in a more localized regression model, whereas a greater bandwidth results in a more global model (220).

GWR facilitates assessment of spatially varying relationships between variables and can be employed to detect spatially dependent relationships that may be overlooked by the conventional regression models. It is principally advantageous when the relationship between variables is spatially dependent and can offer insights into the local factors that influence the dependent variable. While it has been an effective approach in statistics, it does hold some limitations. For instance, the model considers that the correlation between the independent and the independent variables is constant across space, which may not always be the case. Furthermore, GWR can be computationally intensive and may require a large sample size to deliver consistent results. Nevertheless, GWR can provide comprehensions into how the outcomes of variables vary across various locations, which can be valuable for policymakers and businesses.

Based on these attributes, GWR model has been widely used to analyse the connection between socioeconomic and demographic variables, and the solar energy market. In recent reports, GWR has been employed to examine the impacts of demographic and socioeconomic variables on solar panel installation rates, solar energy consumption, and the demand for solar energy (221), (222), (223).

4.10 Cross-sectional Model

Cross-sectional analysis is a type of statistical analysis that examines data from a single point in time, typically involving a group of individuals or objects. It involves collecting data on multiple variables at a single point in time from a set of individuals or entities (224). The significance of the cross-sectional model is to explore the correlation between multiple variables and to identify any patterns or trends that may exist. This model is often used in situations where it is not possible or practical to collect data over an extended period. In the solar energy market, the cross-sectional model has been used extensively to analyse the effects of various socioeconomic and demographic features on the adoption of solar energy. For example, the cross-sectional model has been employed to examine the impact of government incentives, social norms, and environmental attitudes on solar energy adoption (225-227).

Furthermore, it has also been employed to evaluate the relationship between income, education, and household size and their influence on the acceptance of solar energy in households. For this case, data on income, education, and household size are accumulated at a specific point in time, and their relationship to solar energy adoption is scrutinised (228). The results of these studies have provided valuable insights into the factors that influence solar energy adoption and can inform policies and initiatives aimed at promoting the use of renewable energy sources.

4.11 Comparative study and limitations of the statistical models

Each statistical model has its own strengths and weaknesses in analysing the effects of socioeconomic and demographic variables on the solar energy market. Linear regression, logit, and probit models are commonly used in traditional econometric analysis, but they require strong assumptions about the linearity and normally distribution of the data. Furthermore, structural equation modelling is a more complex and comprehensive model that can analyse latent variables and complex causal relationships, but it requires large sample sizes and expertise in statistical analysis. Spatial econometric panel models can capture spatial dependencies and heterogeneity, but they also require specialized knowledge and can be computationally intensive. Decision tree and random forest models are effective machine learning algorithms and have ability to oversee complicated and non-linear relationships, but they are often criticized for being "black box" models that are difficult to interpret. Time-series models can capture dynamic and temporal relationships, but they are sensitive to outliers and can be limited by the amount of available data. Geographically weighted regression is a technique that can explore local variations and non-stationarity, but it entails cautious selection of spatial weights and can be predisposed to overfitting.

As the data for the solar energy market in Australia is taken from the Australian Bureau of Statistics which publishes data after several years, cross-sectional model is found to be more suitable for the study of analysing variables and their impact on solar energy market in Australia. The cross-sectional model confers a significant advantage by enabling the examination of variable relationships at a specific moment, without necessitating temporal monitoring for changes. This makes cross-sectional models particularly useful for studying the impact of demographic and socioeconomic variables on the solar energy market in a specific geographical region or country at a given point in time.

Cross-sectional models offer the advantage of being straightforward to implement and comprehend, rendering them suitable for application across a wider spectrum of data categories. Additionally, it enables the computation of the magnitude and direction of the correlation between variables, furnishing significant insights to decision-makers, financiers, and policy makers. Additionally, cross-sectional models have the capability to accommodate the diversity of observations, offering understanding into the impact of demographic and socioeconomic factors on distinct subpopulations within a given population. In summary, cross-sectional models may offer a simple and easily accessible method for investigating the correlation between demographic and socioeconomic factors and the solar energy industry. This renders them a useful data analysis tool for analysing a wider variety of data sets and use cases. Owning to its numerous advantages and suitability, the cross-sectional model has been extensively utilised in this thesis to examine the correlation between demographic and socio-economic factors and the solar energy market in Australia.

Chapter 5: Methodology

5.1 Research Question

Despite various existing studies on rooftop solar diffusion driven by socioeconomic and demographic variables, there is no study on the change in this socioeconomic and demographic determined diffusion rate due to the unprecedented catastrophe of the COVID-19 pandemic dually impacting the diffusion. First, via unavailability of accredited technicians to install solar (229) and significant logistic disruption (230) following domestic and overseas border closure and obliquely through the change in the influential socioeconomic and demographic variables. However, other contributing factors, such as governmental solar policies and climate change awareness, must be scrutinized to draw a plausible conclusion. Hence, the objective of this project is to investigate and interpret the following principal research question:

"How and to what extent did the COVID-19 pandemic impact the Australian residential solar market?"

This primary research question leads to several detailed questions stated below:

1. What are the driving factors and barriers for residential solar adoption in the existing literature?
2. How did these factors affect the residential solar uptake in Australia during the pandemic?
3. What are the key barriers in the context of COVID-19 pandemic limiting the adoption of residential solar PV in Australia that require dedicated policies to promote greater uptake?

5.2 Research Framework

The research questions mentioned above have been clearly expressed in this section; therefore, the research project is narrowed down to the Australian residential solar market concerning the COVID-19 pandemic. A research framework is needed to lay down a foundation for the research hypothesis and the choice of research method. The significance of the framework is for defining the driving factors that affect a phenomenon of interest and identifying the necessity to study under what conditions and how those driving factors might differ or how those factors impacted the particular phenomenon of interest and their relationship.

The conceptual model representing the key variables and their mutual relationship is shown in Figure 9.

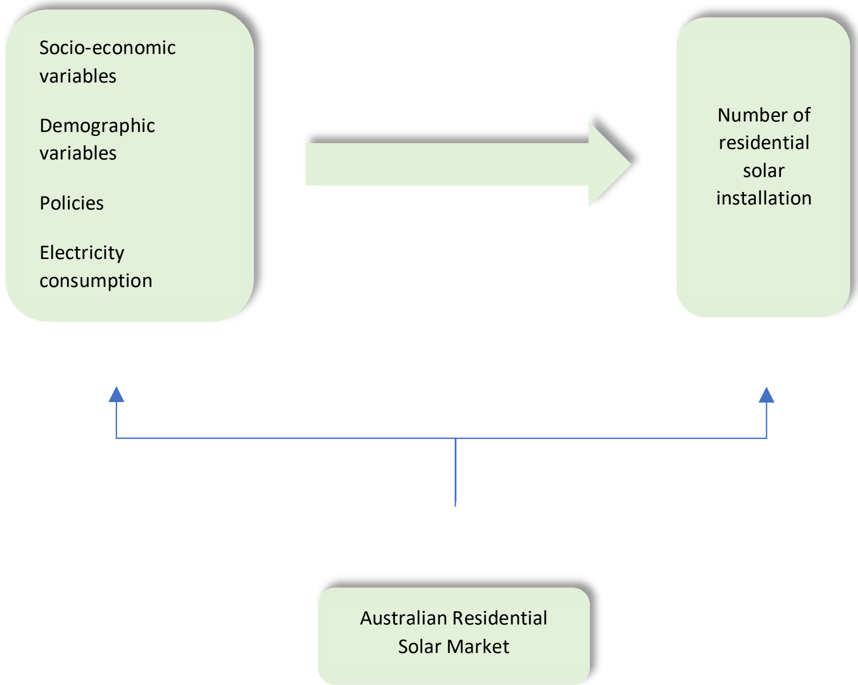

Figure 9. Research Framework

Given the unique global crisis posed by the pandemic (231) (232)to investigate the impact of the unprecedented COVID-19 pandemic on the adoption of rooftop solar PV systems in Australia, this research employs a behavioural framework that integrates the value-belief-norm theory, the theory of planned behaviour, and the diffusion of innovations theory to identify the key attributes influencing residential solar uptake (233) (234)and the potential COVID-19-driven residential solar uptake affecting factors.

Socio-economic and Demographic variables: This set of variables embraces the statistical characteristics of the human population, such as age, population, gender, ethnicity, marital status, household, education, income, employment and homeownership. Comprehensive studies have been done to interpret consumer's behaviour for the diffusion of new technologies indicating the critical role of socioeconomic and demographic variables (64, 235); nevertheless, the primary need is to identify the driving factors influencing the adoption decision.

Based on the elaborative and systematic literature review, variables are selected in Table 1. Several qualitative and quantitative studies have examined the influence of socioeconomic factors on solar PV diffusion. Income inclines to impact uptake (68, 94, 102, 114, 123, 124). Some studies, particularly from Australia, suggests middle-income household are more likely to install solar systems. In contrast, some point in the opposite direction. Other factors like household size can lead to an apparent impact of household income disappearing (236).

The type of dwelling is another significant indicator of adoption (21, 94, 95, 104). Property rights issues are one of the biggest challenges for apartment residents and renters as solar panels are mostly installed on rooftops. However, vertical solar panels are now introduced in the market but are very early. Another feature of households correlated to uptake is the number of bedrooms (81, 101, 104), indicating more electricity demand and greater motivation to install solar panels to avoid higher electricity cost stress.

Education has been included in many pieces of research (68, 81, 99, 124) without much conclusive impact on adoption; still it is suggested to be a significant factor as environmental awareness is correlated with education (237). Age and gender are other unclear factors. Some studies suggest a positive link of age with solar uptake (102, 236). On the other hand, some imply that younger people are more likely to install solar panels (68, 69). About gender, only one study found (66) found the correlation suggesting females tend to install solar more than men, yet gender has been included in various studies (68, 81, 82)

The effect of peers appeared to be an influential driver in adoption (91, 92, 116). Studies suggest solar PV diffusion functions through imitative behaviour and word-of-mouth; also, uncertainties regarding various aspects of solar uptake reduces when trusted adopters convey their positive experience.

Policies: Solar uptake is an investment behaviour to cut electricity costs involving investment, payback, and risk. The decision is made based on rational market analysis and related policies. Subsidies are found to be a significant driver for uptake (69, 82, 104, 140) in various studies since the upfront cost of installation is an obstacle for households especially with medium to lower-income which are more likely to adopt to avoid electricity cost. Feed-in-tariff, on the other hand, is the most extensively studied and impactful driver (14, 17, 130, 134) since investment decision depends principally on projected payback time; lowering FiTs increases this period influencing the decision while encouraging battery adoption behaviour at the same time.

Electricity Cost: Electricity price tends to affect solar adoption (21, 97, 112, 129) playing a significant role in adoption decision due to financial stress from electricity bills apart from return on investment through FiTs saving via self-consumption motivating consumers with higher consumption (102). Since residential electricity consumption has increased during the pandemic, electricity cost appears to be an influencing factor in the light of existing literature.

5.3 Research Methodology

On account of the research questions and the limitation on the socioeconomic and demographic variables, data being available through the census every five years, Cross Section Regression Model is selected for this study. A cross-section study is an inferential method to describe the plausible relationship between the explanatory and response variable at a single point in time, referred to as a snapshot of a specific group of individuals at a predetermined moment of time. Another significance of its selection is its ability to study numerous parameters simultaneously in a current population (176, 238).

5.3.1 Data acquisition

The data on stringency levels across the country during a pandemic is available from the States Government Department of Health media release (239-246). Census data from the Australian Bureau of Statistics (ABS) is acquirable for demographic, social and economic variables (247). Australian Government Clean Energy Regulator (AGCER) provides the data on the number of residential solar installations (248). APVI publicly delivering postcode solar installation data of Australia (249) is another source to cross-validate the data. Moreover, states Feed-in Tariff and Solar Rebates details can be obtained from annual reports published by APVI (250).

5.3.2 Australian Government Clean Energy Regulator

The clean energy regulator (CER) is the governmental body accountable for implementing strategic direction, regulatory schemes and policies to increase carbon abatement by empowering renewable energy frameworks and businesses. It publishes multiple types of data related to power generation through renewable energy sources such as solar energy. As the solar electricity business transactions happen in the form of certificates, REC publishes a broad range of data related to solar business, system installation, generated and installed capacity.

5.3.3 The Australian PV Institute

The Australian PV Institute (APVI) is a non-profit institute that provides reliable and independent information and data about solar energy uptake and helps support the development of solar photovoltaics and linked technologies. In coordination with various governmental, industrial and academic organisations, it publishes multiple types of solar uptake data of the Australian solar uptake monthly and yearly. Specifically, detailed insights about solar uptake, especially in light of COVID-19 pandemic effects, and could help policymakers make better decisions to facilitate solar energy business and uptake. It provides data in different sections as follows:

Live Solar PV performance data from Australia-wide PV installation, monthly and annually PV potential for the urban region, percentage of houses or buildings with solar systems and installed capacity by postcode, monthly charts for PV installation systems that are registered under the RET scheme, monthly PV installation data by capacity size and postcode across Australia.

All sorts of this data may help investigate the demand, supply, uptake and utilisation of electricity generated through solar systems and may provide a better understanding of solar energy parameters, business and market variations during the COVID-19 pandemic.

5.3.4 Australian Bureau of Statistics

The Australian Bureau of Statistics (ABS) conducts a census for its inhabitants every fine year, covering various social, economic, and demographic topics. As these topics are critical parameters for understanding the Australian population's behaviour, progress, and inclination towards a specific project, they might possess critical information to understand the solar energy business better. The latest census was held on 10 August 2021, with the data release dates in multiple phases in June 2022, Oct 2022 and early to mid-2023. As the census data has details of the socio-economic and demographic variables before and during the COVID-19 epidemic, it will be of prime importance to analyse and investigate their implications on the solar energy business. The details of the data are as follows:

5.4 Econometric Model

COVID-19 outbreak, apart from its severity, mortality rate, and transmissibility, is an antecedent to many governmental restrictions and lockdowns with various levels of severity that have impacted businesses (251). To determine the effect of COVID-19 on the Australian solar PV market, stringency level categorical variables coded by dummy variables will be included in the Cross-section regression model (82), ranging from low to high with no restrictions as the base (252). Similarly, dummy variables for the duration of lockdown in a postcode will be used to build a coherent model where the variation in the length of lockdowns across Australia will determine the number of categories, setting no lockdown as the reference. Moreover, its correlation with the number of solar PV installations is employed as a proxy to estimate the impact of COVID-19 on solar uptake. Unlike (253), to evaluate the significance and magnitude of the COVID-19 pandemic contingent change in residential solar uptake in Australia more rigorously, restriction levels and length of lockdowns are divided into two different categorical variables. However, the number of COVID-19 cases may also be included in the model to determine pandemic related delays.

$$Y_p = L_p\alpha + R_p\beta + S_p\Upsilon + E_p\delta + D_p\varepsilon + P_p\zeta + \eta_p$$

Y_p = the number of solar PV installation per postcode.

L_p = binary variables for the length of lockdown

Research Question	Model	Approach	Data Source
Key influential factor affecting the residential solar uptake	N/A	Literature review	Academic journals, book chapter, and conference proceedings, Official Reports and Media releases
Nature of COVID-19's impact	Contemporaneous model w/o control variables	(Active) Lockdown duration Var. and no. of avg. past two-years Install.	States Government Media releases, Australian Government Clean Energy Regulator (AGCER)
COVID-19's impact	Contemporaneous model with control Var.	(Active) Lockdown duration Var., no. of avg. past two-years Install., SE, DEMOGR, Policy Control Var	States Government Media releases, Australian Government Clean Energy Regulator (AGCER), Australian Bureau of Statistics (ABS)
	Lag Model	Lagged lockdown duration Var., no. of avg. past two-years Install., SE, DEMOGR, Policy Control Var.	States Government Media releases, Australian Government Clean Energy Regulator (AGCER), Australian Bureau of Statistics (ABS)
COVID-19 associated influential factors	Contemporaneous Interaction model	Lagged lockdown duration Var., no. of avg. past two-years Install., SE, DEMOGR, Policy Control Var., (Active) Lockdown duration Var. * Control Var.	States Government Media releases, Australian Government Clean Energy Regulator (AGCER), Australian Bureau of Statistics (ABS)
	Lag Interaction model	Lagged lockdown duration Var., no. of avg. past two-years Install., SE, DEMOGR, Policy Control Var., Lagged Lockdown duration Var. * Control Var.	States Government Media releases, Australian Government Clean Energy Regulator (AGCER), Australian Bureau of Statistics (ABS)

R_p = binary variables for the restriction/stringency level

S_p = Socioeconomic variable

E_p = Economic variable

D_p = Demographic variable

P_p = Policy variable

η_p = error term

α, β, ϒ, δ, ε, ζ = parameters need fitting

However, in order to investigate research question 2, i.e. the impact of COVID-19 associated change in socioeconomic and demographic variables on the Australian residential solar market interaction terms $L_p \times R_p \times S_p$ and $L_p \times R_p \times D_p$ will be used to generate two separate interaction models (254-265).

Moreover, a similar model will be used for the economic variable since household income among the economic variable has changed in the wake of the increase in the unemployment rate across Australia during the pandemic as shown in Table 3.

Table 3. Research methodology

Alternatively, the ANOVA test will be used to find out the plausible effect of COVID-19 lockdowns on residential solar installation across Australia (266-268) with the Tukey Post Hoc test (269, 270) to investigate the stringency level and the lockdown duration impact.

After a substantive selection of the explanatory factors through a detailed literature review data, sourcing plays a vital role in factor screening because of two reasons the unavailability of data for a few variables and the data preparation processing is constrained by the project's time limit.

Consequently, the Demographic variables defined in section 4 include Population, Age, Gender, Marital status, and Australian Citizenship Status. The Social variable includes education, language, household size, and type of dwelling, whereas economic variables include total household income, house ownership status, employment status, household expenditure, and electricity price. Last, is the policy variables embracing Feed-in-Tariff and Solar Rebates.

5.5 Statistical Tests and Checks

Regression analysis is a mathematical relationship between one or more explanatory variables and a response variable, but it’s worth rests on the model's significance, reliability and validity. Statistical testing used to check the significance of the model is defined by the type of variables, data structure and distribution. At the same time, the reliability and validity of the model require checks for correlation among the explanatory variables and the goodness of fit tests how the set of data fits the selected model.

5.5.1 Statistical Significance Test

P-value will be used for Null hypothesis testing defining whether there is any relationship among the study variables. The variables are included in the model if the p-value is small; otherwise, the null hypothesis is true and suggests eliminating the variable.

5.5.2 Variance inflation factor (VIF)

Multicollinearity affects the statistical significance of the regression coefficient estimation. In a multiple regression model, there is a high probability of correlation among the independent variables. The variance inflation factor evaluates multicollinearity among the explanatory variables of a multiple regression model (271) as the ratio of the variance of an individual explanatory variable model to the variance of the whole model hence, its contribution toward the standard error.

5.5.3 R square (coefficient of determination)

R squared, also called the coefficient of determination, measures goodness-of-fit, the difference between the fitted values and the set of observations. It estimates the model and the dependent variable relationship strength on a scale of 0-100%. Generally, the higher the R-squared value, the better the observation data fits the model and vice versa, yet, this is not always the case. Sometimes a good regression model has a low R-squared value, and a high value can be due to some problem in the model. Alone R-squared is not enough to assess the model.

Chapter 6: New South Wales Test Model

In order to scrutinize the integrity of the research design, assess the suitability of the chosen variables in terms of their efficacy in attaining the research objectives, evaluate the methodology employed, appraise the model selection, and test the design of the COVID variable which constitutes the principal component of this study a preliminary analysis is conducted utilizing data from New South Wales, the most populous state in Australia (272).

6.1 Method

6.2 Model and Variables

Cross section model is for this project as the impact of COVID-19 on the Australian residential solar market spanned for two years therefore, a snapshot of the residential solar market during this time is necessary to determine the effect of pandemic on the market.

$$Y_p = L_p\alpha + R_p\beta + S_p\Upsilon + E_p\delta + D_p\varepsilon + P_p\zeta + \eta_p + C \tag{1}$$

Y_p = the number of solar PV installation per postcode (p).

L_p = binary variables for the length of lockdown

R_p = binary variables for the restriction/stringency level

S_p = Socioeconomic variable

E_p = Economic variable

D_p = Demographic variable

P_p = Policy variable

η_p = error term

C = Constant

α, β, Υ, δ, ε, ζ = parameters need fitting

To identify and analyse the change in solar PV uptake trend before and during the pandemic, the natural logarithm of the number of residential solar installations per postcode is used as the dependent variable, with the natural logarithm of the previous two-year averaged number of solar installations as an explanatory variable representing the residential solar growth before the pandemic. Furthermore, given that the lockdowns imposed during the COVID-19 outbreak were temporary, short-term, and sporadic with varying intensity in nature, therefore, to estimate the effect of these lockdowns on solar PV uptake trend short time periods for the dependent and the explanatory variable of number of solar installations. Where number of installation explanatory variables is determined by the two-year average of installations preceding the onset of the pandemic i.e. 2018 and 2019. However, the selection of analysis period is done following the months lockdown was implemented and consequent the rises and dips in the number of residential solar installations trend as shown in *Figure 10*

$$\ln Y_p = \ln X_p + L_p\alpha + S_p\Upsilon + E_p\delta + D_p\varepsilon + P_p\zeta + C_p\theta + \eta_p \qquad (2)$$

Four time periods are chosen for the year 2020: January to March, the pre-pandemic period and before the implementation of lockdown measures; April and May, the lockdown period; June to August, following the end of the lockdown; and September to November, due to the unusual rise and dip in solar installations trend during September and October, respectively as shown in *Figure 10*. A similar strategy is employed for the year 2021: January to March is a steady increase interval, April to June is the gradual decline of installations and the pre-lockdown period, July to September is the lockdown, and September to November is due to a sharp rise in solar installations in September. In addition, the government started to lift the lockdown in some regions of New South Wales in September, and the lockdown restrictions started to ease due to the development of the COVID-19 vaccination and the subsequent rising vaccination rate. However, the National model would employ a similar approach, using the National number of residential solar installations chart.

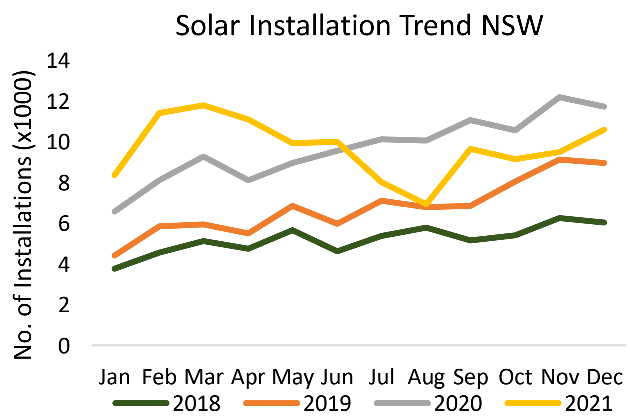

Figure 10 No. of solar PV installations in NSW per month in 2018, 2019, 2020, and 2021, typical household solar PV. No. of installations increased in 2019 compared to 2018. However, the rise in 2020 no. of installations is much higher, showing rises and dips that deviate from the patterns observed in previous years following the lockdown timing. Unlike previous years in March 2020, before the lockdown, installations increased, with more unusual surges and drops in June, September, and October 2020. In contrast, the 2021 deviation from the previous trend is more significant, with a more sustained increase from January to June 2021, with a sharp dip in August 2021, followed by a sharp rise in September 2021.

6.3 The COVID variable

The data on stringency levels across the country during a pandemic is available from the States Government Department of Health media release (239, 241-246). However, for NSW postcode data on stringency level across New South Wales is collected from NSW Government websites including Ministerial media releases (273), Department of Education (274), and Parliament of Australia (275). In addition, broadcasting media websites was also used to acquire missing information on the length and accurate dates of the lockdown and restrictions in regional areas on Government websites.

Due to the lack of accurate data on COVID-19 restrictions for regional New South Wales, the stringency level variable Rp has been eliminated from the model. Thus, only the total number of days in lockdown defines the COVID categorical variable, with largest number of lockdown days coded as 1 as the reference. Ten-day lockdown ranges are used to define a category with the exception for category 4 where construction activities were paused, which included the installation of residential solar. This pause was a significant hindrance to the installation in these postcodes. As category 4 also had a stay-at-home lockdown followed by a curfew, the pause on construction had an even greater impact on the ability of residents to install solar panels in their homes.

The data on lockdowns during the pandemic is available by LGA but the study is designed for postcode data to get more detailed and precise information hence, better estimate of the impact of COVID-19 on solar PV uptake during the pandemic. To accurately defining each COVID cluster and to determine more precise estimate of the impact postcodes crossing an LGA were mapped by assigning ratio to the overlapping postcodes using the postcode to LGA data provided by Australian Bureau of Statistics (276). However, postcode mapping is not included in the model due to high multicollinearity it has caused in the test analysis. Consequently, postcode to LGA ratio was used to determine the COVID cluster for the overlapping postcodes assigning the postcode to the LGA which includes greater proportion of the postcode.

6.4 Socioeconomic and demographic variables

The demographic variable D encompasses age, population size, gender, and marital status(94, 95, 114). As shown in ***Table 4***, the social variable S includes household characteristics such as household size, dwelling structure and type, number of children per family, number of bedrooms, and level of education.

The economic variable (E) is comprised of the total household income, home ownership status, weekly rent, employment status and mortgage payment. Moreover, Small-scale renewable energy scheme subsidy zones solely denote the policy variable as the energy retailers are allowed to offer competitive feed-in-tariff rates making the current, accurate feed-in-tariff data collection infeasible to the project timeline. However, since the pandemic duration was relatively short, feed-in-tariff rates are less likely to be changed significantly compared to the pre-pandemic rates. Census 2021 data from Australian Bureau of Statistics is used for socioeconomic and demographic variables (277).

Table 4. Selected variables with definition

Variable	Definition
Population	Population size of the postcode.
Married	The proportion of married people in a postcode.
Female	The proportion of females in a postcode.
Age 35 to 55 years	The proportion of people in a postcode aged between 35 years to 55 years.
Age 55 and over	The proportion of people in a postcode aged 55 years and over.
University or tertiary	The proportion of people with university or tertiary education in a postcode.
High school	The proportion of people with high school education only in a postcode.
Year 8 or below	The proportion of people with the highest education of year 8 or below in a postcode.
Owned outright	The proportion of dwellings owned outright in a postcode.
Owned with mortgage	The proportion of dwellings owned with mortgage in postcode
Rented with real estate	The proportion of dwellings rented from real estate agent in a postcode.
Rented with community	The proportion of dwellings rented from community housing provider in a postcode.
Rented with state housing	The proportion of household rented from the State or territory housing authority in a postcode.
Separate houses	The proportion of separate houses in a postcode.
Duplexes	The proportion of duplexes in a postcode.

Flats	The proportion of units/apartments/flats in a postcode.
Occupied dwellings	The proportion of occupied dwellings in a postcode.
Unoccupied dwellings	The proportion of unoccupied dwellings in a postcode.
One or less bedroom household	The proportion of studio or one-bedroom household in a postcode.
Two bedrooms household	The proportion of household with two bedrooms in a postcode.
Three or more bedrooms household	The proportion of household with three or more bedrooms in a postcode.
One-person household	The proportion of one-person household in a postcode.
Two persons household	The proportion of two persons household in a postcode.
Three-persons household	The proportion of three persons household in a postcode.
Four persons household	The proportion of four persons household in a postcode.
Five or more persons household	The proportion of five or more than five persons household in a postcode.
One-child family	The proportion of families with one child in a postcode.
Two children family	The proportion of families with two children in a postcode.
Three or more children family	The proportion of families with three or more than three children in a postcode.
Unemployed	The proportion of unemployed people in a postcode.
Employed with part-time work	The proportion of people employed with part-time work in a postcode.
Employed with full-time work	The proportion of full-time employed people in a postcode.
Low income household	The proportion of household with total annual income AUD 20,799 or below in a postcode.
Middle income household	The proportion of household with total annual income range between AUD 20,800 to AUD 77,999 in a postcode.
Higher income household	The proportion of household with total annual income range between AUD 78,000 to AUD 181,999 in a postcode.
Rent up to 350	The proportion of household with weekly rent up to AUD 350 in a postcode.

Rent up to 550	The proportion of household with rent AUD 351 to AUD 550 in a postcode.
Rent up to 750	The proportion of household with rent AUD 551 to AUD 750 in a postcode.
Rent up to 950 and above	The proportion of household with rent AUD 950+ in a postcode.
Mortgage repayment up to 1999	The proportion of household with monthly mortgage repayment up to AUD 1,999 in a postcode.
Mortgage repayment up to 2999	The proportion of household with mortgage repayment up to AUD 2,999 in a postcode.
Mortgage repayment up to 3999	The proportion of household with mortgage repayment 3,000 to AUD 3,999 in a postcode.
Mortgage repayment 4000 and above	The proportion of household with mortgage repayment 4,000 and above in a postcode.
SRES Subsidy Zone	The SRES subsidy zone number of a postcode 1, 2, 3, and 4.

Factor screening was performed using the variance inflation factor (VIF) and considering the research question at hand. Variables with a VIF value exceeding 10 were dropped after thoroughly analysing their significant association with the research question. Nevertheless, to avoid model under-fitting by eliminating too many variables, which might lead to the reduced explanatory power of the model to capture the complexity of the underlying relationship between dependent and independent variables. Averaged variables were created for quantitative variables like the number of children, number of bedrooms, rent, mortgage repayment, and number of persons and ordinal variables like income, but VIF value remained high. Therefore, binary coded variables were created to resolve the multilinearity issue, using the median as a threshold hence, categorizing observations into two groups based on whether their value is above or below the median value, setting below the median value as a reference. Finally, Age 35 – 54, Age 55 and over, gender with male as reference, University Education, High-School Education, Low income households, Middle income households, Higher income household, Married, One or less bedrooms household, Two bedrooms household, Three or more bedrooms household, Owners, Owners with mortgage, Separate houses, Duplexes, Two or less persons household, Four persons household, Six persons household, Eight or more persons household, Population, One child family, Two children family, Three or more children family, and SRES Subsidy Zone variables are selected.

Whereas, the variable **C** is the number of cases per postcode. The data is collected from New South Wales Government website Data.NSW (278).

6.5 Climate change attitude variable

The proportion of votes for environmental political parties (82, 96) in the 2022 federal election was used as a proxy for people's attitude and concern towards climate change. This data was obtained from the Australian Electoral Commission(279). However, to avoid further reduction in sample size, which is already a concern due to the presence of COVID clusters in the data, this variable was excluded from the current analysis. Nevertheless, it may be considered for a national model.

In addition to the Variance inflation factor (107) and normal quantile-quantile (QQ) plot (280), the Doornik-Hansen test is used to check for skewness and kurtosis of the residuals (281) and the Breusch-Pagan/Cook-Weisberg test for heteroskedasticity (282). However, to account for any heteroskedasticity, the logarithm transformation of the dependent variable and the average before COVID-19 number of installations and robust standard errors are used.

6.6 Results and Discussion

6.6.1 Results without socio-economic controls

Table 5illustrates the change in residential solar uptake trend during 2020. Cluster 2 exhibits a statistically significant positive estimate of 0.359 at a 5% level, implying growth in solar installation compared to the previous two years. Given the dependent variable has been transformed using the natural logarithm, thus the coefficient is calculated using the formula (exp(A1) - 1) * 100, for equation *(3)*. This suggests an almost 43 percent rise in residential solar uptake during the first quarter of 2020 among the postcodes of cluster 2. The rising trend persisted for 2020 and 2021, with a slight decline during June to August 2020 period while July to September 2021 lockdown had a relatively greater effect on uptake as shown in Table 6.

$$\ln(Y)=A0 + A1*X + v \sim B \qquad (3)$$

The duration of lockdown is correlated with the growth of rooftop solar adoption in cluster 1 and 2, which consist of postcodes in the northern beaches of Sydney where lockdown was implemented during the last week of December and the first week of January as evident from Table 5 and Table 6. The solar PV uptake trend shows an increase after the December lockdown in these clusters, as shown in Table 6. However, there was a subsequent drop of varying intensity in both clusters during the second lockdown.

Table 5. Results of COVID Clusters residential solar installations during 2020.

	ln number of solar installations Jan - Mar 2020	ln number of solar installations Apr - May 2020	ln number of solar installations Jun - Aug 2020	ln number of solar installations Sep - Nov 2020
Number of cases in March 2020	735.7			
COVID Cluster 1	0.258	0.223	0.34	0.647**
COVID Cluster 2	0.359**	0.677***	0.500***	0.674***
COVID Cluster 3	0.0223	0.0228	0.16	0.204*
COVID Cluster 4	0.365***	0.265***	0.449***	0.565***
COVID Cluster 5	0.403***	0.275**	0.407***	0.227***
COVID Cluster 6	0.402***	0.448***	0.148	0.386**
COVID Cluster 7	0.0256	0.154	0.251*	0.0982
COVID Cluster 8	0.163	0.295*	0.176	0.166
COVID Cluster 9	0.0728	0.0176	-0.139	0.0748
COVID Cluster 10	0	0	0	0

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10.*

Table 6 illustrates that there was a more noticeable increase in solar PV uptake in 2021, which could be attributed to the ongoing restrictions. Postcodes with longer lockdown periods had stricter restrictions, especially in Local Government Areas (LGAs) of concern, with the exception of Cluster 4. This cluster, which includes the postcodes with the most severe stay-at-home lockdowns and curfews, experienced the highest surge in solar PV adoption, with a coefficient of 0.704, or around 102%, at a significance level of 1%. The trend of residential solar uptake experienced the most significant decline during the second lockdown, when construction activities were halted by the government, which affected Cluster 4 the most, as the construction ban lasted longer in these areas.

Table 6. Results of COVID Clusters residential solar installations during 2021.

	ln number of solar installations Jan - Mar 2021	ln number of solar installations Apr - Jun 2021	ln number of solar installations Jul - Sep 2021	ln number of solar installations Sep - Nov 2021
Number of cases during January - March 2021	5708.8			
COVID Cluster 1	0.535***	0.532***	0.279**	0.698*
COVID Cluster 2	0.394**	0.637***	0.463*	0.671***
COVID Cluster 3	0.384***	0.347**	0.115	0.321**
COVID Cluster 4	0.704***	0.545***	0.195*	0.648***
COVID Cluster 5	0.461***	0.386***	0.266***	0.382***
COVID Cluster 6	0.321**	0.386**	0.385***	0.461**
COVID Cluster 7	0.187	0.149	0.231*	0.303***
COVID Cluster 8	0.0933	0.0128	0.235	-0.0582
COVID Cluster 9	0.0239	-0.035	-0.119	0.0579
COVID Cluster 10	0	0	0	0

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10.*

6.7 Results with socio-economic controls

6.7.1 Northern Beaches Sydney region

The linear regression analysis was conducted to examine the impact of COVID-19 on residential solar uptake while controlling for key influential socioeconomic and demographic factors. Group 10 of COVID cluster having the least number of days of lockdown was set as reference. Cluster 1, comprising northern postcodes of North Beaches Sydney region with a small number of postcodes and a small population, experienced the longest duration of lockdown among all the clusters. However, the sample size for this cluster was relatively small, which could be a reason for the insignificant coefficients observed for 2020 and 2021 as shown in Table 7 and Table 8.

Table 7. Results of residential solar installations during 2020.

	ln number of solar installations Jan - Mar 2020	ln number of solar installations Apr - May 2020	ln number of solar installations Jun - Aug 2020	ln number of solar installations Sep - Nov 2020
Number of cases in March 2020	-893			
SRES Subsidy Zone	0.07	0.0725	0.0639	-0.0216
Age 35 - 54	-0.0837	-0.0311	0.0432	0.000944
Age 55 and over	-0.00909	0.0995	0.0325	-0.0131
Gender	0.193**	0.146**	0.113*	0.0904
University Education	0.0949	0.0691	0.00889	0.0838
High-School Education	0.0958	0.0263	-0.161*	-0.0198
Low income households	-0.0652	-0.0631	-0.0813	0.0336
Middle income households	0.0126	0.0547	0.033	0.0714
High income household	-0.0538	-0.0263	-0.0371	-0.0587
Married	-0.0528	0.0451	0.0269	0.0152
One or less bedrooms household	-0.144*	-0.108	-0.0445	-0.00493
Two bedrooms household	0.00994	0.119	-0.013	-0.0522

Three or more bedrooms household	0.248**	0.213**	0.0513	0.182**
Owners	-0.0738	-0.0727	-0.022	-0.0192
Owners with mortgage	0.0694	0.0137	-0.0632	-0.0123
Separate houses	0.0311	0.0915	0.00531	-0.0901
Duplexes	-0.051	0.0395	0.0168	-0.0149
Two or less persons household	-0.333***	-0.188**	-0.316***	-0.202**
Six persons household	-0.163*	-0.0432	-0.0123	-0.0481
Four persons household	-0.162	0.0225	0.0717	0.0233
Eight or more persons household	0.123*	0.0984	0.155**	0.147*
Population	0.0000138***	0.0000126***	0.0000100***	0.0000109***
One child family	0.16	-0.0772	0.114	-0.056
Two children family	0.155	0.134	0.103	0.087
Three or more children family	-0.0571	-0.0386	-0.0507	-0.0738
COVID Cluster 1	-0.19	-0.129	0.053	0.429
COVID Cluster 2	-0.0938	0.325*	0.0838	0.370*
COVID Cluster 3	-0.444***	-0.236	-0.164	-0.0682
COVID Cluster 4	-0.109	-0.00619	0.0792	0.302**
COVID Cluster 5	0.115	0.106	0.149	0.124
COVID Cluster 6	0.117	0.326*	0.0785	0.284*
COVID Cluster 7	0.0505	0.162	0.250*	0.124

COVID Cluster 8	0.156	0.293*	0.192	0.151
COVID Cluster 9	0.0612	-0.00265	-0.149	0.0644
COVID Cluster 10	0	0	0	0

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10*

Cluster 2 consisted of thirteen postcodes comprising the southern suburbs of Sydney's Northern Beaches. Even though it is relatively larger than cluster 1, yet still has a smaller sample size. Similarly, cluster 6 encompasses eighteen postcodes of Newcastle and cluster 8, and cluster 8 comprises a minor portion of regional New South Wales with only thirteen postcodes.. During the first lockdown and before the second lockdown of this region, the rooftop solar deployment raised by 0.677 and 0.637, as compared to 0.359 and 0.394 respectively. The reason for this significant growth might be the panic buying of the potential prosumer, as reported by a New South Wales residential solar retailer. (283).Nevertheless, cluster 2 followed similar trend since the implementation of COVID-19 lockdowns was geographically associated, and the socioeconomic and demographic features of the population are spatially related, it is possible that other explanatory variables included in the model are explaining the same variable. This may explain the insignificant cluster coefficient during 2021, despite the coefficients remaining significant throughout the year in the COVID Cluster model, as depicted in Table 6. For instance, number of persons and number children were positively related to an increase in solar PV uptake consistent with one of the previous study (81). Note that the number of children is not a much-studied variable and is included in this study because of its relation to the research question.

Table 8. Results of residential solar installations during 2021.

	ln number of solar installations Jan - Mar 2021	ln number of solar installations Apr - Jun 2021	ln number of solar installations Jul - Aug 2021	ln number of solar installations Sep - Nov 2021
Number of cases during January - March 2021	-829.4			
SRES Subsidy Zone	0.319*	0.0921	-0.0534	0.440**
Age 35 - 54	-0.0273	-0.108	0.0695	-0.0878
Age 55 and over	0.0815	0.0324	0.0892	0.0397

Gender	0.0467	0.0326	0.101	0.224***
University Education	0.0913	0.0781	0.117	0.143*
High-School Education	-0.0917	0.078	-0.0749	-0.0388
Low income households	0.013	-0.05	-0.0333	0.0509
Middle income households	0.0965	0.058	-0.0363	0.00735
High income household	0.00905	-0.132	-0.0788	-0.103
Married	0.0432	0.137*	0.0772	0.0835
One or less bedrooms household	-0.0665	-0.0665	-0.0324	-0.0984
Two bedrooms household	0.028	0.0573	-0.0133	-0.0974
Three or more bedrooms household	0.275***	0.0403	0.0763	-0.0509
Owners	-0.0889	-0.172**	-0.0638	-0.00729
Owners with mortgage	-0.078	-0.07	-0.111	-0.00932
Separate houses	0.0329	-0.00828	-0.115	-0.0424
Duplexes	-0.0484	0.0864	0.000665	-0.00927
Two or less persons household	-0.459***	-0.297***	-0.272***	-0.266***
Six persons household	-0.144	0.0588	-0.101	0.0226
Four persons household	-0.00299	-0.187	-0.029	0.104

Eight or more persons household	0.144*	0.0625	0.181**	0.0852
Population	0.0000174***	0.0000142***	0.0000127***	0.0000125***
One child family	0.0401	0.0941	0.0195	0.0496
Two children family	0.153	0.219*	0.267**	0.0792
Three or more children family	0.0524	0.133	0.0124	0.00185
COVID Cluster 1	0.282	0.148	-0.176	0.301
COVID Cluster 2	0.108	0.0615	-0.179	0.16
COVID Cluster 3	0.0337	-0.18	-0.416**	-0.0694
COVID Cluster 4	0.316**	0.0387	-0.323**	0.213*
COVID Cluster 5	0.221*	0.193*	-0.0167	0.162
COVID Cluster 6	0.292*	0.157	0.178	0.332*
COVID Cluster 7	0.240**	0.109	0.217*	0.284***
COVID Cluster 8	0.175	0.0093	0.175	0.0412
COVID Cluster 9	-0.0187	-0.0346	-0.142	-0.0106
COVID Cluster 10	0	0	0	0

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10.*

6.7.2 Greater Sydney region

Cluster 3 mostly remained insignificant, with a decline in solar PV adoption by 0.44 and 0.419 before the first lockdown and during the second lockdown, respectively as shown in Table 7 and Table 8. It's important to note that this cluster apart from a few postcodes of regional NSW mostly includes the local government areas of Randwick, Woollahra, Waverley, and the City of Sydney. Randwick is known for having a high student population, while the City of Sydney is largely a commercial area with high-rise apartments, making it less likely for residents to install solar due to limited roof space.

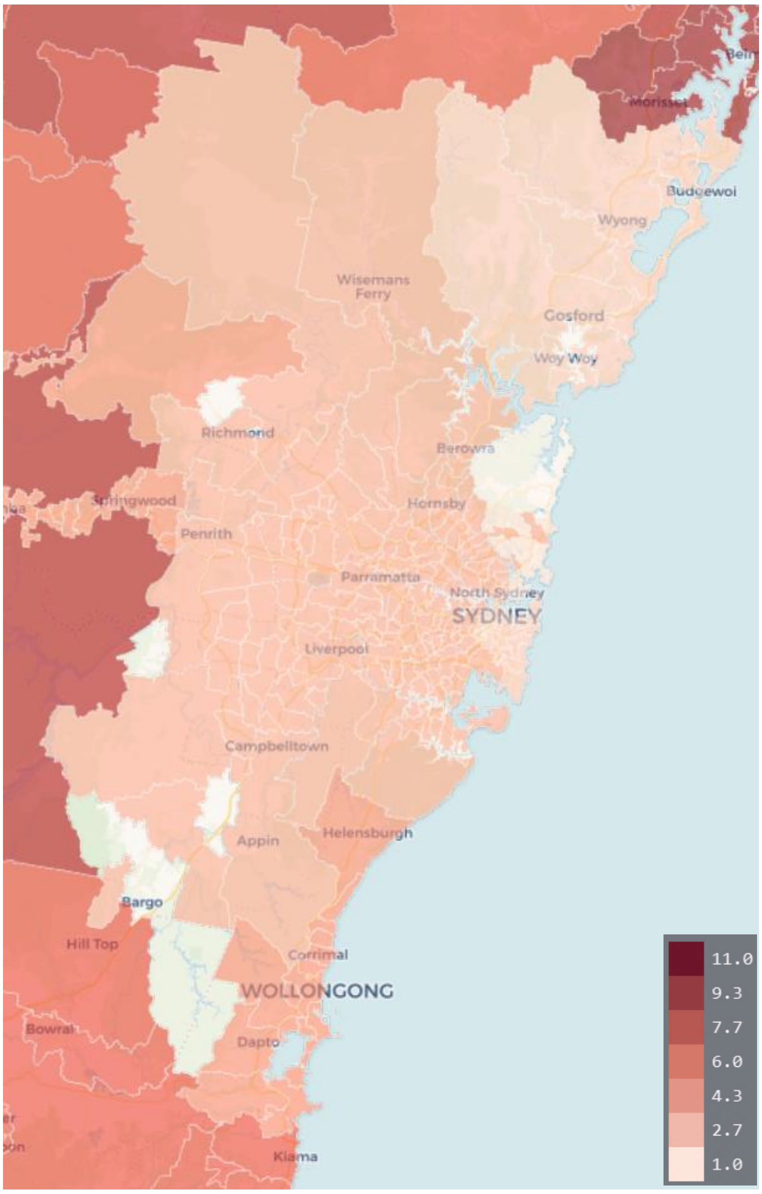

Figure 11. Heat map of Greater Sydney showing the length of lockdown with 1.0 indicates the postcodes with longest and 11.0 shows the shortest lockdown.

However, COVID-19 was positively associated with cluster 4 during September to November 2020, with an increase in the number of installations by 0.302 as shown in Table 7. This cluster continued the increased uptake trend associated with COVID-19 during the first quarter of 2021, as shown in Table 8 with a 0.316 increase at a significant level of 5%. However, the decline during the second lockdown by almost 0.323 was expected, as previously mentioned, due to construction being put on hold during this lockdown. Furthermore, this cluster is located in the region with the harshest lockdowns in New South Wales. But the rising trend quickly revived soon after restrictions on construction industry started easing from September, with a 0.213 increase.

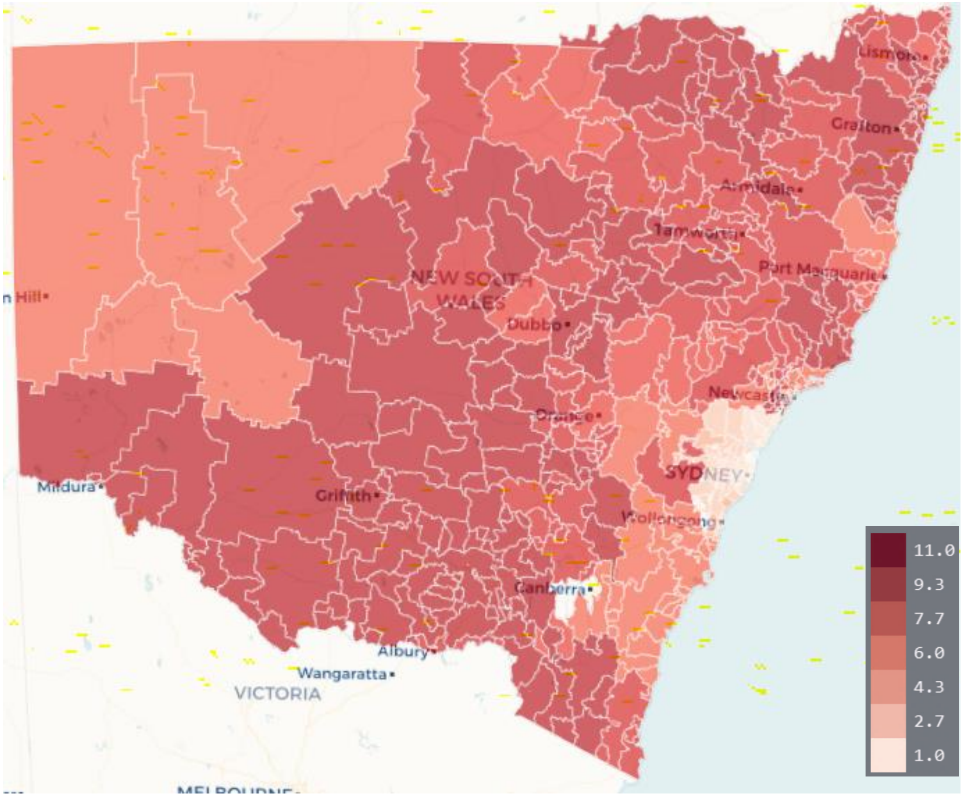

Figure 12 Heat map of New South Wales showing the length of lockdown with 1.0 indicates the postcodes with longest and 11.0 shows the shortest lockdown.

Cluster 5, showed a positive association with COVID-19 during the first half of 2021, prior to the last lockdown in Australia.

6.7.3 Newcastle region

Nonetheless, for Cluster 6, there was a 0.326 and 0.248 surge in residential solar installations during the first lockdown of Australia and the last quarter of 2020, respectively, which was correlated with COVID-19 as shown in Table 7. Moreover, the positive COVID-19-associated uptake trend increased to almost 0.292 and 0.332 as shown in Table 8 for the first quarter and after the second, which was the longest lockdown period.

6.7.4 Regional NSW

The solar PV adoption trend for cluster 7 was more consistent, with mostly around a 0.25 COVID-19 correlated surge since after the first lockdown period as shown in Table 7. In conclusion, the one-year long restrictions followed by more stringent measures during the Christmas 2020 and 2021 New Year period impacted the solar PV adoption trend significantly during 2021. This impact was particularly evident in clusters with larger sample sizes and for Greater Sydney postcodes. However, COVID-19 had less impact on regions with shorter lockdown durations, such as clusters 8 and 9.

6.7.5 Relationship with the control variables

In addition to the COVID-19 correlation with residential solar uptake during the pandemic gender, number of bedrooms, number of people, number children, education, SRES subsidy zone, home ownership, and marital status had significant relationship with the adoption behaviour. Postcodes with more female were more likely to install rooftop solar as in existing literature (114) the significant relationship for most of the 2020 and last quarter of 2021. Higher education was positively correlated as found in other studies (120, 284), solar PV uptake trend dropped by 0.16 in postcodes that share more people with high school education only after first lockdown and solar adoption was higher, as indicated by the coefficient of 0.143 among the people with university education after second lockdown. As individuals with a university education are likely to get employed in jobs that allow for remote work, making them spend more time at home and consume more electricity, which may incentivize them to install solar PV systems.

Postcodes with households containing a greater number of bedrooms installed 0.182 – 0.248 more rooftop solar during 2020 as shown in Table 7 which is consistent with previous studies (81, 82). However, this variable was not significant for most of 2021 as shown in Table 8 except for the first quarter. This could be attributed to people getting used to spending more time at home, or other possibilities such as those who were more concerned about electricity costs had already installed solar panels. It is also possible that those who did not install solar panels care less about the bills or have higher incomes.

Home ownership was positively correlated with residential solar uptake aligned with existing literature (14) from April to June 2021 at the significance level of 5%. Postcodes with a greater proportion of houses owned outright had 0.172 lower solar PV adoption. One possible explanation of these counter-intuitive results could be the small size of the cluster or the omitted variables might have been the cause. Increasing the sample size may resolve this issue. Households with married people installed 0.137 were residential solar than household with unmarried people during April to June 2021 time period. Whereas SRES subsidy zone had positive coefficient of 0.32 and 0.44 at the significance level of 10% and 5% for first and last quarter of 2021 as shown in Table 8. The reason might be NSW has only three SRES subsidy zones with zone four has relatively very small number of postcodes. Or it is possible that there is a correlation with an unobserved variable.

6.7.6 COVID/socio-economic interactions

For interaction model an interaction term for each socioeconomic, demographic and policy variable is used in the model to determine the interaction of COVID-19 lockdowns with the key drivers of residential solar adoption during the pandemic. Average values to binary code the quantitative variables including number of people, number of children, and number of bedrooms. Age had strong interaction with the COVID lockdown duration on rooftop solar adoption with 0.05, 0.057, and 0.044 at the significance level of 10%, 5%, and 10% respectively as shown in Table 9 and Table 10 Postcodes with shorter lockdowns and higher proportion of middle-aged residents installed more solar PV during the lockdowns and also after the first lockdown as indicated in other studies (94). For the reason that middle-aged individuals are more likely to have families and greater financial responsibilities such as mortgage payments, were more inclined to work from home during the pandemic and engage in home schooling, hence increased the diffusion of rooftop solar since shorter lockdowns make have impacted the employment less and hence, the financial stability. Also, theses postcodes might have more opportunities for residential solar uptake consultation However, the COVID-19 had a negative interaction of 4.8% with age 55 and over, indicating older individuals were less likely to install solar in postcodes with shorter lockdowns during 2021. This may be due to the fact that older individuals typically spend more time at home already therefore, were less affected by stay-at-home measures, in addition to having lower income levels compared to middle-aged individuals.

Table 9.Results of interaction of COVID-19 lockdown variable with socioeconomic and demographic variables 2020.

	Apr - May 2020	Jun - Aug 2020	Sep - Nov 2020
COVID*Age 35 - 54	0.0508*	0.0577**	-
COVID*Age 55 and over	-	-	-
COVID*Gender	0.0449*		
COVID*University Education	0.0467*	0.0525**	-
COVID*High-School Education	-	-	-
COVID*Separate houses	-0.0540**	-0.0394*	-0.0560**
COVID*Number of children	-	-0.0571**	-0.0325*
COVID*Number of bedrooms	-	-0.0575**	-0.0594**
COVID*Number of persons	-	-	-

COVID*Owners with mortgage	-	-	-
COVID*Duplexes	-	-	-
COVID*Owners	-	-	-

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10*

According to Table 9 university-educated individuals adopted residential solar at a 4.8% and 5.4% higher rate during and after the initial shutdown. This may be attributable to their higher income levels, allowing them to invest in residential solar. Another possibility might be their raised awareness of the environmental benefits of residential solar uptake, resulting in an increased motivation to invest in renewable energy sources. The estimate was only statistically significant at the onset of the pandemic, suggesting people's elevated concerns regarding the uncertainty of solar panel availability in future due to border closures might have led to "panic buying" of solar PV.

Table 10. Results of interaction of COVID-19 lockdown variable with socioeconomic and demographic variables 2021.

	Jan - Mar 2021	Apr - Jun 2021	Jul - Sep 2021	Sep - Nov 2021
COVID*Age 35 - 54	-	-	0.0442*	-
COVID*Age 55 and over	-	-	-0.0495*	-
COVID*Gender				0.0487*
COVID*University Education	-	-	-	-
COVID*High-School Education	-	-	0.0491*	
COVID*Separate houses	-	-	-0.0700***	-
COVID*Number of children	-0.0397*	-	-	-
COVID*Number of bedrooms	-0.0717***	-	-0.0655***	-0.0469*
COVID*Number of persons	-0.0637**	-0.0404*	-	-

COVID*Owners with mortgage	-0.0435*	-0.0405*	-0.0379*	-
COVID*Duplexes	-	-	0.0365*	0.0455*
COVID*Owners	-	-	-0.0504**	-

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10.*

Interaction term for separate houses have negative coefficients as shown in Table 9 and Table 10Table 36 and Table 37. Similarly, number of children, number of persons, and number of bedrooms as shown in Table 9 and Table 10. Families with more children or persons living in postcodes with longer lockdowns had to spend more time at home with home-schooling, work-from-home, and involved more in children entertainment activities which might have amplified their energy bills stimulating them to take control of their energy costs and uptake solar. In addition, COVID-19 has driven the economic crisis, stimulating those with more capital to invest in rooftop solar. Likewise, residents of separate houses and dwellings featuring more bedrooms tend to have larger families and greater responsibilities, contributing to their inclination towards rooftop solar investment. These elements may explain these variables' length of lockdown associated negative correlation with rooftop solar adoption during this time. Home ownership showed the same relationship as shown in Table 10. However, occupants of duplexes have positive interaction with the duration of COVID lockdowns. Duplexes residents installed 3.7% and 4.7% approximately more solar PV in postcodes with shorter lockdowns as shown in Table 10. Furthermore, SRES subsidy policy had no interaction with COVID lockdown duration.

Chapter 7: National Level Model

7.1 Methodology

Since the COVID cluster variable was created using the total number of days of lockdown, which was not temporally aligned with the period of the number of solar installations used in the study. This might have affected the accuracy and determination power of the model. Therefore, a new lockdown duration variable is designed for the National model.

Nevertheless, to investigate the effect of COVID-19 on the residential solar market in Australia, meticulously, additional models, as mentioned below, are used for this analysis.

1- Contemporaneous model without Control Variables

2- Contemporaneous model with Control Variables

3- Lag Model

4- Contemporaneous Interaction Model

5- Lag Interaction model

Since the information on the number of COVID-19 cases was not available for all states thus, the variable is eliminated from this model.

7.1.1 Contemporaneous model without Control Variables

To determine the change in residential solar uptake in correlation with lockdown duration contemporaneous model without socioeconomic, demographic, and policy control variables is used. The model is the same as used for the New South Wales test analysis with the natural logarithm transformed number of residential solar installations as the dependent variable with the natural logarithm transformed average of the past two years before the pandemic number of solar installations is used as an explanatory variable. The lockdown duration variable is the difference in this model compared to the New South Wales model.

For the national model, the lockdown duration variable is designed as previously a categorical variable, whereas, for this variable, each analysis period includes the clusters based on the cumulative lockdown days for that particular timeframe throughout Australia. As a result, the distinct group for each temporal interval encompasses diverse postal codes, depending on the length of confinement measures in those specific regions during that timeframe. This methodological improvement is anticipated to enhance the congruity between the exogenous and endogenous variables, thereby reinforcing the precision and strength of the model's ability to examine the relationship between lockdown length and residential solar diffusion during the pandemic.

A seven-day active lockdown interval defines each cluster, with cluster 1 being the reference, thus encompassing the minimum lockdown duration of the national model as shown in *Table 11*. The lockdown duration variable is designed as previously a categorical variable, whereas, for this variable, each analysis period includes the clusters based on the level of lockdown measures implemented during that particular timeframe throughout Australia.

Table 11. Lockdown duration variable design

Lockdown Duration variable			
Statistics		**Group**	**No. of Days**
Max.	91	1	0-6
Min.	0	2	7 - 13
Range	91	3	14 - 20
Range values	7	4	21 - 27
		5	28 - 34
		6	35 - 41
		7	42 - 48
		8	49 - 55
		9	56 - 62
		10	63 - 69
		11	70 - 76
		12	77 - 83
		13	84 - 90
		14	91 - 97

7.1.2 Contemporaneous model with Control Variables

To investigate the effect of COVID-19 on residential solar uptake with a better degree of robustness, socioeconomic, demographic, and policy variables are added to the contemporaneous. Controlling for confounding factors is a crucial aspect of econometric modelling as it helps to mitigate the influence of variables that may be impacting both the dependent and independent variables, ultimately enhancing the precision of the model. Consequently, it enhances the validity and reliability of the findings.

7.1.3 The Variables

7.1.3.1 Construction Ban Variable

Since during July 2021 to October 2021, construction was put on hold in several States of Australia at different times, hindering the residential solar installations in the corresponding postcodes during these months. To quantify this impact while isolating it from the general lockdowns, seven days of construction ban are used to describe a category, as shown in *Table 12*, with group one as the base to improve the model's accuracy.

Table 12. Construction Ban Variable Design.

Construction Ban Variable			
Statistics		**Group**	**No. of days**
Max	24	1	0 - 6
Min	0	2	7 - 13
Range	24	3	14 - 20
Range Value	7	4	21 - 27

However, the socioeconomic, demographic, and policy variables included are the same as test model as shown in *Table 13*

Table 13. Socioeconomic, demographic, and policy variable in the model.

Variable	**Definition**
Population	Population size of the postcode.
Married	The proportion of married people in a postcode.
Female	The proportion of females in a postcode.
Age 35 to 54 years	The proportion of people in a postcode aged between 35 years to 55 years.
Age 54 and over	The proportion of people in a postcode aged 55 years and over.
University Education	The proportion of people with university education in a postcode.
High school	The proportion of people with high school education only in a postcode.
Owned outright	The proportion of dwellings owned outright in a postcode.
Owned with mortgage	The proportion of dwellings owned with mortgage in postcode
Separate houses	The proportion of separate houses in a postcode.

Number of bedrooms in a dwelling	The average number of bedrooms in dwellings of a postcode.
Number of persons in a dwelling	The average number of persons in dwellings of a postcode.
Number of children in a family	Averaged number of children in families of a postcode.
Unemployed	The proportion of unemployed people in a postcode.
Average total household income	The average total household income of a postcode
SRES Subsidy Zone Rating	The SRES subsidy zone ratings i.e. 1.622, 1.536, 1.382, 1.185 of a postcode.

7.1.3.2 Population

The population size of a postcode is included as an indicator of the potential residential solar market size of the postcode. Since the number of residential solar in depends on the number of potential prosumers in an area, it is essential for the robustness of the model to control for this demographic characteristic of a postcode.

7.1.3.3 Marital Status

Given that, not only the energy consumption and available capital of the households with married couples might be different, but also, the decision-making process of these households could be more complex than those who are single.

7.1.3.4 Female

As some existing literature on residential solar diffusion suggests, women are more likely to uptake solar (114, 285), possibly due to their more significant concerns regarding environmental issues. Therefore, based on the effect of gender on the decision-making of residential solar diffusion, the proportion of females in a postcode is included in the model.

7.1.3.5 Age

Two separate variables are included for this demographic feature of the population, as the existing literature suggests that the residential solar adoption rate is relatively higher among middle-aged individuals (94). On the other hand, a few studies suggested the positive association of older age with solar uptake (114, 286). Apart from its significance in literature, the pandemic impact on the residential market could be correlated with these age groups and might be in different ways. For instance, middle age people have a higher probability of having more financial responsibilities and bigger households; thus, the COVID-19-induced financial and employment crisis, in addition to remote-working and home-schooling during this time, might have affected this group's solar uptake decision.

For older people, the odds are higher that they depend on pensions and might also own a dwelling with no mortgage repayments. They could be less impacted by the pandemic financially but have a greater opportunity to install solar on their rooftops over the duration of the lockdown. Increasing energy costs could have affected these individual’s perspective towards residential solar uptake.

7.1.3.6 Education

Education has two categories in the model: high school education and university education. High school education only encompasses individuals with no university degree but may have diplomas and certificates qualifications though. Due to the reason that these individuals may have fewer opportunities to continue their jobs remotely, the COVID-19 crisis might have affected these individuals' solar uptake decisions more.

Conversely, university education was previously associated with higher solar uptake (120, 284), but the pandemic may have changed this relationship. However, due to its past significant correlation with solar adoption, it is imperative to control for this characteristic of the population to determine the COVID-19 impact accurately.

7.1.3.7 House ownership

The proportion of individuals with houses that are owned outright and owned with a mortgage are incorporated in the model separately; however, due to the collinearity issue, the model does not use control for renters as the proportion of renters is indicated by one minus the proportion of owners.

House ownership with a mortgage is used due to the additional financial stress of mortgage on the households, which may encourage them to uptake solar for energy cost saving, especially during the pandemic. Even though the mortgage repayments for households with financial hardships were deferred, complicating its relationship with solar adoption.

7.1.3.8 Types of dwelling

The proportion of separate houses is the only control added for housing type. These households have relatively more opportunity to install solar so are more likely to be the potential solar market and could impact the number of installations. This is especially the case during the lockdowns times since the workers would have been able to install solar while fulfilling the physical distancing or even no contact with residents of the households. The model does not incorporate units/apartments and duplexes due to the collinearity issue.

7.1.3.9 Number of bedrooms

Apart from their significance from the existing literature (81, 82), he size of the dwelling with more bedrooms might have motivated people to adopt residential solar to control their energy bills since they are predisposed to a pandemic-driven consumption increase.

7.1.3.10 Household size

The model includes the number of persons and the number of children independently to account for a household size effect on the residential solar uptake decision. The number of person influences is evident from the previous study (81). In contrast, the pandemic, a shock to habitation and an economic crisis due to its plausible association with heightened energy consumption might have aggravated its significance to residential solar diffusion.

On the other hand, the number of children is included in the model as the number of persons consists of adult individuals who are likely to be involved in the uptake decision apart from the rise in energy consumption association. Also, these individuals might or might not be employed, influencing the household's financial capacity to bear the upfront cost of installations. Living in the same household, these adult individuals might be affecting the potential size of the residential solar market. At the same time, children are unlikely to participate in decision-making and are more likely to be associated with the financial constraints of a household. Consequently, one group's barrier might be the driving factor of the other group. Note that this variable is not used in nearly all previous studies.

7.1.3.11 Household total income

Aside from the evident significance and nature of the correlation of household income with residential solar deployment, this socioeconomic characteristic of a population is extensively studied (95, 116, 124). Nevertheless, because both the variable and solar installation is capital associated, signifying the need to control for this variable for the model's robustness.

7.1.3.12 Unemployment Status

As suggested by the literature (69), the employment status variable is included in the model, recognising that the financial instability caused by the pandemic might have influenced the decision to adopt solar systems.

7.1.3.13 SRES Subsidy Zone Rating

Since the existing literature suggests a strong relationship between an increase in the number of residential solar installations and Small-scale renewable energy scheme zone ratings (82), the variable is added to the model. However, the variable is pivotal in the context of this study as the pandemic triggered economic uncertainty might have made this subsidy more attractive to people and subsequently have upsurged the residential solar deployment during this time.

7.2 Lag effect Model

The lag model determines the delayed effect of an independent variable on the target variable. Moreover, the dynamic relationship between the independent and target variable can only be defined by the lag model; therefore, considering the nature of the study, this model is used to evaluate the delayed response of individuals to the COVID-19 lockdowns induced lifestyle change might consequently heighten the energy cost of many households. Given that the lockdowns were sporadic and residential solar uptake is a long-term investment decision thus, the lockdown duration influence on the residential solar deployment is prone to have a delayed effect. COVID-19 was a shock to habitation; therefore, individuals might have taken some time to adapt to the new life norms, evaluate their financial standings, collecting all the necessary information on residential solar installations, including the potential government support, financial incentives, and the procedure of residential solar uptake. Therefore, the lag model is included to account for the time required for the decision-making and the plausible delays in installations due to the supply chain disruption, the COVID-19 restrictions on the construction industry, and the skilled worker shortage, which a contemporaneous model cannot scrutinize.

Subsequently, to investigate this delayed effect, the accumulative days of past lockdowns are used for each period. Unlike the categorical lockdown duration variable used in the contemporaneous model, the lagged lockdown duration variable used in this model is a continuous variable. However, the same control variables are used in this model as in the contemporaneous model with control variables.

7.3 Contemporaneous Interaction Model

The Contemporaneous Interaction Model is a statistical model used to analyse the combined impact of multiple independent variables on a dependent variable simultaneously within the same time frame. In order to examine the COVID-19-induced barriers and driving factors to residential solar deployment during the pandemic contemporaneous interaction model is used where the interaction term for each control variable is generated with the active lockdown duration variable and used individually for each period.

Given that interaction terms are used to examine whether the effect of an explanatory variable on the dependent variable is heterogeneous across different levels of another explanatory variable, the model will determine how the extent of the lockdown affected the socioeconomic, demographic, and policy variable influence on the residential solar deployment.

The cross-section regression model can potentially identify the role of an individual's income, employment status, education, type of residence Etc. with solar adoption behaviour during the pandemic; however, the role of these variables might have with the length of lockdown experienced by these individuals. This plausible change in solar adoption behaviour is valuable for policy implication considering the influence of these explanatory variables are likely to be interdependent.

7.4 Lag Interaction model

As discussed earlier, the lag variable is used to capture the correlation of the dependent and independent variable that may have evolved over time; therefore, the contemporaneous interaction model might not be enough to scrutinize the solar adoption behaviour of people during the pandemic especially when the lockdown length was different in different postcodes. Similar is the case for determining the interaction effect of these variables. These demographic and socioeconomic features' role in residential solar uptake could be different with a delay involved.

The residents of the postcodes where the lockdown was implemented for an extended period might be able to get residential solar installed later after the lockdowns even though they might have made the decision earlier. This is especially the case when considering not only the decision-making process but also the installation process, which is quite long, especially amid the pandemic.

Lagged lockdown duration variable is used to define the interaction term for this model following the same methodology as used for the contemporaneous interaction model, i.e. using each interaction term individually for every period.

Hence, the temporal trends and dynamics that may not be evident in the contemporaneous interaction model can be revealed via the lagged model yielding a more sophisticated comprehension of the determinants that drive the adoption of solar panels, encompassing the lagged effects of these covariates.

Chapter 8: Results and Discussion

This chapter presents the results of four different models' Contemporaneous model without control variables, Contemporaneous model with control variables, Lag model, and Interaction model followed by discussion.

8.1 Contemporaneous model without Control Variables

The association of the duration of lockdown with the change in residential solar uptake trend during 2020 is shown in *Table 14*. Given that the length of lockdown during January 2020 to March 2020 was too short to affect the residential solar uptake i.e. one day only, this time period has not been included in this analysis.

Table 14. Results of Lockdown Duration Clusters 2020

	ln number of solar installations Apr - May 2020	ln number of solar installations Jun - Aug 2020	ln number of solar installations Sep - Nov 2020
	(1)	(2)	(3)
Lockdown Duration Cluster 1		0	0
Lockdown Duration Cluster 2		-0.0713	
Lockdown Duration Cluster 3			-0.102**
Lockdown Duration Cluster 4	0		-0.132
Lockdown Duration Cluster 5	0.112*		
Lockdown Duration Cluster 6	0.137**		
Lockdown Duration Cluster 7	0.0239		
Lockdown Duration Cluster 8		0.0435	

Lockdown Duration Cluster 9	0.188	-0.373***
Lockdown Duration Cluster 10		
Lockdown Duration Cluster 11		
Lockdown Duration Cluster 12		
Lockdown Duration Cluster 13		
Lockdown Duration Cluster 14		

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10.*

April 2020 to May 2020 time period included four clusters i.e. Cluster 4, Cluster 5, Cluster 6, and Cluster 7. Cluster 4 including postcodes with 21 to 27 days of lockdown has minimal days of lockdown and hence set as the reference cluster in the regression. The coefficients for Cluster 5 and Cluster 6 indicate a rise in residential solar uptake is associated with an increase in the lockdown duration in these regions. Lockdown duration cluster 5 as shown in Table 15 comprised primarily of Queensland postcodes, along with a few from Northern Territory. Conversely, Cluster 6 predominantly consists of postcodes from three states: South Australia, followed by Tasmania, with the Australian Capital Territory contributing a minor portion to the cluster. In contrast, Lockdown Duration Cluster 7 exhibits a more even distribution of postcodes from both New South Wales and Victoria, along with only two postcodes from the Australian Capital Territory, as shown in *Table 15*. This cluster demonstrates no evidence of the impact of the lockdown period on the number of solar installations in these areas during this time, suggesting that the first lockdown might have affected the number of solar installations in New South Wales and Victoria less as the construction workers were included in the essential workers who had the exemption to continue their work during the lockdown.

Table 15. April 2020 to May 2020 Lockdown Duration Clusters Composition

April 2020 – May 2020			
Cluster	**State**	**No of Postcodes**	**Percentage of Total Postcodes**
Cluster 4	Reference	383	15.14%
Cluster 5	Northern Territory	45	1.78%

	Queensland	282	11.15%
Cluster 6	South Australia	343	13.56%
	Tasmania	116	4.59%
	Australian Capital Territory	27	1.07%
Cluster 7	New South Wales	632	24.99%
	Victoria	699	27.64%
	Australian Capital Territory	2	0.08%

June 2020 to August 2020 includes only the two clusters other than the base cluster, Cluster 1. All these clusters are single State clusters of Victoria, as shown in *Table 16*, where Cluster 9 includes only 10 postcodes of Melbourne. However, the results show no evidence of a relationship between lockdown duration and residential solar uptake.

Table 16. June 2020 to August 2020 Lockdown Duration Clusters Composition

June 2020 – August 2020			
Cluster	**State**	**No of Postcodes**	**Percentage of Total Postcodes**
Cluster 1	Reference	1881	74.38%
Cluster 2	Victoria	377	14.91%
Cluster 5	Northern Territory	1	0.04%
Cluster 8	Victoria	260	10.28%
Cluster 9	Victoria	10	0.40%

The study identified four distinct clusters in the second half of 2020, notably from September to November, corresponding to a period well into the first year of the COVID-19 pandemic. Except for Cluster 1, the reference cluster, the remaining three clusters (Cluster 3, Cluster 4, and Cluster 9), are single State clusters of Victoria, with Cluster 4 encompassing merely eleven postcodes as shown in *Table 17*, is the smallest. Cluster 3 and Cluster 9 estimates illustrate strong negative relationship of residential solar uptake with length of lockdown in these clusters of Victoria suggesting longer lockdowns lead to decrease in number of solar installations during this period.

Table 17. September 2020 to November 2020 Lockdown Duration Clusters Composition

September 2020 – November 2020			
Cluster	**State**	**No of Postcodes**	**Percentage of Total Postcodes**

Cluster 1	Reference	1859	73.51%
Cluster 3	Victoria	389	15.38%
Cluster 4	Victoria	11	0.43%
Cluster 9	Victoria	270	10.68%

The results for December 2020 to March 2021, as shown in Table 18, suggest the significant effect of lockdown duration on residential solar deployment for Cluster 4, consisting of only nine postcodes of New South Wales, as shown in *Table 19*, the estimate indicates extent of lockdown associated growth in residential solar uptake. In contrast, Cluster 3, with similar attributes except for duration of lockdown, demonstrates an insignificant estimate.

Table 18. Results of Lockdown Duration Clusters 2021

	ln number of solar installations Dec 2020 - Mar 2021 (4)	ln number of solar installations Apr - Jun 2021 (5)	ln number of solar installations Jul - Sep 2021 (6)	ln number of solar installations Sep - Nov 2021 (7)
Construction Ban			-0.0399	
Lockdown Duration Cluster 1	0	0	0	0
Lockdown Duration Cluster 2		-0.198***	0.0295	-0.293***
Lockdown Duration Cluster 3	0.187	0.186***	-0.00517	-0.0587
Lockdown Duration Cluster 4	0.388*		-0.056	-0.179*
Lockdown Duration Cluster 5			-0.143**	-0.185
Lockdown Duration Cluster 6			-0.155*	0.249***
Lockdown Duration Cluster 7			0.0503	0.432***
Lockdown Duration Cluster 8			0.491	-0.0164

Lockdown Duration Cluster 9	0.223
Lockdown Duration Cluster 10	0.280***
Lockdown Duration Cluster 11	
Lockdown Duration Cluster 12	
Lockdown Duration Cluster 13	0.104
Lockdown Duration Cluster 14	0.128

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10.*

Similarly, the results for April 2021 – June 2021 imply a strong relationship between lockdown duration and residential solar adoption. The estimates for Cluster 2 indicate a significant negative impact (-0.198***) on residential solar deployment in these postcodes, suggesting that the number of solar installations declined with increased lockdown duration in this cluster, a single State cluster of Victoria, as shown in *Table 20*. On the contrary, Cluster 3, encompassing the postcodes of single State of Victoria too, shows evidence of a strong positive correlation between the length of the lockdown and the number of residential solar installations in these postcodes of Melbourne, with a coefficient of 0.186.

Table 19. December 2020 - March 2021 Lockdown Duration Cluster Composition

December 2020 – March 2021			
Cluster	**State**	**No of Postcodes**	**Percentage of Total Postcodes**
Cluster 1	Reference	2511	99.29%
Cluster 3	New South Wales	9	0.36%

Cluster 4	New South Wales	9	0.36%

The lockdown from July 2021 to September 2021 was followed by a pause in the construction industry for varied duration across Australia; however, there is no evidence of the impact of the construction ban on residential solar uptake in this model. Regarding the lockdown duration clusters, Clusters 5 and 6 illustrate a lockdown duration-driven fall in the number of residential solar installations, as shown in *Table 18*. Both the clusters have similar composition, consisting of postcodes of New South Wales, Victoria, and the Australian Capital Territory, with the only difference of Cluster 6 having fewer postcodes of the Australian Capital Territory, i.e. two, as shown in *Table 21*. In contrast, Cluster 10, a single State cluster of Victoria, indicate significant correlation between rise in residential solar adoption and extent of lockdown during this period with a coefficient of 0.242.

This period includes the largest number of clusters; nevertheless, most of the States except Victoria, New South Wales, and the Australian Capital Territory fall in Cluster 1 and Cluster 2. Cluster 2 show no evidence of a correlation between the residential solar adoption and lockdown duration. The relatively short duration of lockdowns in these states might be the contributing factor to this lack of correlation. Therefore, potential solar adopters could still have sufficient time to install residential solar.

Table 20. April 2021 - June 2021 Lockdown Duration Cluster Composition

April 2021 – June 2021			
Cluster	**State**	**No of Postcodes**	**Percentage of Total Postcodes**
Cluster 1	Reference	1859	73.51%
Cluster 2	Victoria	400	15.82%
Cluster 3	Victoria	270	10.68%

The estimates for Cluster 2 imply extended lockdown are strongly correlated with fewer rooftop solar installations in these postcodes as shown in *Table 18* during September 2021 to November 2021 period. The high statistical significance of the coefficients implies a high degree of confidence in the relationship, indicating that longer lockdowns might have had an evident negative impact on the number of solar installations in areas corresponding to Cluster 2. Although the correlation is not as significant as in Cluster 2, the estimate for Cluster 4 suggests that the longer duration of lockdowns is associated with lower solar installations in these postcodes. The statistical significance of the coefficient still implies the negative effect of longer lockdowns on the residential solar market in the postcodes of Cluster 4.

However, the positive and significant coefficient for Cluster 6 suggests that extended lockdowns may have substantially impacted the residential solar market in the regions corresponding to Cluster 6. It could be attributed to the fact that the previous period was the most extended and most stringent lockdown for New South Wales, which encompasses almost half the cluster; therefore, during this period, these postcodes might have been catching up and could be a delayed response to the earlier decision of uptake. The estimate of Cluster 7 aligns with Cluster 6, signifying the rise in residential solar uptake in these regions. Future research could investigate these response differences among clusters 2 and 4 and 6 and 7.Examining the composition of these clusters, clusters 2 and 4 have almost similar composition comprising of Victoria and New South Wales the postcodes as shown in The results suggest that during the beginning of COVID-19, the lockdowns impacted the residential solar installations in the States of Queensland, Northern Territory, Tasmania, and the Australian Capital Territory, where the residential solar uptake was positively associated with the length of lockdown in these States except for Cluster 5 during June 2020 to August 2020 which included only one postcode of Northern Territory had a negative impact.

Table 22 with addition of only two postcodes of the Australian Capital Territory in Cluster 4. On the contrary, Clusters 6 and 7 are single State clusters of New South Wales and the Australian Capital Territory. Moreover, the insignificance of Cluster 8, a single State cluster of Victoria, implies no evidence of a relationship between the solar deployment and the lockdown duration within Victoria during this particular timeframe. While the results suggest correlation between the duration of lockdown and number of solar installations in New South Wales and the Australian Capital Territory.

Table 21. July2021 - September 2021 Lockdown Duration Cluster Composition

July 2021 – September 2021			
Cluster	**State**	**No of Postcodes**	**Percentage of Total Postcodes**
Cluster 1	Reference	626	24.75%
Cluster 2	Queensland	201	7.95%
	South Australia	343	13.56%
Cluster 3	Victoria	355	14.04%
Cluster 4	New South Wales	1	0.04%
	Victoria	34	1.34%
Cluster 5	New South Wales	210	8.30%
	Victoria	11	0.43%
	Australian Capital Territory	27	1.07%

Cluster 6	New South Wales	51	2.02%
	Victoria	14	0.55%
	Australian Capital Territory	2	0.08%
Cluster 7	New South Wales	65	2.57%
	Victoria	15	0.59%
Cluster 8	New South Wales	1	0.04%
Cluster 9	New South Wales	18	0.71%
Cluster 10	Victoria	270	10.68%
Cluster 13	New South Wales	36	1.42%
Cluster 14	New South Wales	249	9.85%

The results suggest that during the beginning of COVID-19, the lockdowns impacted the residential solar installations in the States of Queensland, Northern Territory, Tasmania, and the Australian Capital Territory, where the residential solar uptake was positively associated with the length of lockdown in these States except for Cluster 5 during June 2020 to August 2020 which included only one postcode of Northern Territory had a negative impact.

Table 22. September 2021 - November 2021 Lockdown Duration Cluster Composition

September 2021 – November 2021			
Cluster	**State**	**No of Postcodes**	**Percentage of Total Postcodes**
Cluster 1	Reference	1170	46.26%
Cluster 2	New South Wales	168	6.64%
	Victoria	353	13.96%
Cluster 3	New South Wales	59	2.33%
	Victoria	42	1.66%
Cluster 4	New South Wales	27	1.07%
	Victoria	23	0.91%
	Australian Capital Territory	2	0.08%
Cluster 5	New South Wales	28	1.11%
	Victoria	11	0.43%
Cluster 6	New South Wales	349	13.80%
Cluster 7	Australian Capital Territory	27	1.07%
Cluster 8	Victoria	270	10.68%

The Australian Capital Territory illustrated similar results of a robust upward relationship, indicating that the extended lockdowns were associated with increased solar installations. However, during July 2021 - September 2021, this relationship turned negative, suggesting that an increase in lockdown duration led to a decrease in solar installations. This fluctuation in the relationship could be attributed to various factors, such as different stages of the pandemic, changes in policy, public awareness, consumer behaviour, or other external influences. However, it is only possible to pinpoint the exact reasons for this fluctuation by considering additional socioeconomic, demographic, and policy variables. In the subsequent analysis, we will explore these additional factors' impact to understand better the underlying dynamics of the relationship between lockdown duration and solar installations.

In the case of New South Wales, the results for 2020 suggest no evidence of any relationship between the duration of lockdowns and solar installations. However, lockdowns have started to negatively impact residential solar uptake in Victoria as evident by the results shown in *Table* 14 The insignificant results may be attributed to a combination of factors that counterbalanced the anticipated negative relationship. For instance, the panic buying of solar panels during the first lockdown (283) might be counterbalanced by the disruption in the supply chain for solar panels (287). Or it could be possibly due to heterogeneous impacts, i.e. the effects of supply chain disruptions and uncertainty were distributed unevenly across various geographic areas or market sectors. Some regions or types of solar installations may have exhibited greater resilience to disruptions, resulting in a varied impact on the overall residential solar market.

Nevertheless, the results for these states were more varied in 2021, with lockdown duration and the number of installations showing positive, negative, and statistically insignificant results across different clusters and periods. This variation in the correlation between lockdown duration and the number of installations might be due to other contextual factors, unobserved regional differences in these clusters, or potential interactions among the variables.

In addition, socioeconomic and demographic factors and environmental awareness might also have shaped the relationship between lockdown duration and the number of solar installations in these states. The results of the Contemporaneous model with socioeconomic and demographic control variables, the Lagged model, and Interaction model will be analysed to better understand the relationship between lockdown duration and solar installations, exploring additional variables or interactions that might contribute to the observed inconsistencies.

8.2 Contemporaneous model with Control Variables

In order to examine the change in socioeconomic and demographic control variables during the two years of COVID-19 pandemic the January 2020 to March 2020 period is included in this model.

Table 23. Results of Contemporaneous model with Control Variables 2020.

	ln number of solar installations Jan - Mar 2020	ln number of solar installations Apr - May 2020	ln number of solar installations Jun - Aug 2020	ln number of solar installations Sep - Nov 2020
	(1)	(2)	(3)	(4)
Age 35 - 54	-0.442	0.934	0.628	0.696
Age 55 and over	0.0649	0.652*	0.827**	1.489***
Married	-1.306**	-0.593	-0.408	-0.866*
Separate houses	-0.322*	0.0485	-0.216	-0.490***
University Education	1.240***	0.493	0.494	1.135***
High School Education	0.836*	1.304**	0.764	0.834*
Gender	2.308***	3.350***	3.530***	2.084***
Unemployed	0.83	3.167	-1.285	1.826
Household Income	-0.00000423***	1.29E-07	-0.00000246*	-0.00000331***
Number of Bedrooms	0.272***	0.146	0.224**	0.379***
Number of Children	0.059	0.0425	-0.270*	-0.177
Number of Persons	0.162	0.162	0.437***	0.408***
Population	0.0000153***	0.0000156***	0.0000144***	0.0000131***
Owned outright	0.2	-0.566*	-0.770***	-0.694***
Owned with mortgage	0.876***	-0.0356	-0.0583	0.395
SRES Subsidy Zone Rating	0.595***	1.034***	0.603***	0.547***
Construction Ban				
Lockdown Duration Cluster 1	omitted		0	0
Lockdown Duration Cluster 2			-0.000643	
Lockdown Duration Cluster 3				-0.00911
Lockdown Duration Cluster 4		0		-0.161
Lockdown Duration Cluster 5		0.09	-1.800***	
Lockdown Duration Cluster 6		0.235***		
Lockdown Duration Cluster 7		0.0865		

Lockdown Duration Cluster 8	-0.0168	
Lockdown Duration Cluster 9	-0.0401	-0.434***
Lockdown Duration Cluster 10		
Lockdown Duration Cluster 11		
Lockdown Duration Cluster 12		
Lockdown Duration Cluster 13		
Lockdown Duration Cluster 14		

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10.*

The first COVID-19 lockdown implemented on 31 March 2020 across Australia was of a single day. Consequently, the period from January 2020 to March 2020 exhibited only one cluster, i.e. Cluster 1, encompassing all the nationwide postcodes. Therefore, the cluster was omitted from the analysis since it acted as a constant and a reference for reliable interpretation, avoiding any multicollinearity issue.

Cluster 4 serves as the base cluster for Australia's first COVID-19 lockdown. Of the other three clusters, Cluster 6 demonstrates a significant positive correlation with an estimate of 0.235 at the confidence level of 1%, suggesting that longer lockdowns in this cluster correspond to an increased number of residential solar installations during this period.

However, Cluster 5 illustrated significant correlation between lockdown duration and the number of residential solar installations as shown in *Table 14*, before including the socioeconomic, demographic, and policy variables. However, after incorporating these control variables, the statistical significance of the Cluster 5 diminished as shown in *Table 23*. This suggests that the observed correlation between lockdown duration and residential solar uptake in Cluster 5 may have been driven or confounded by the effects of these additional factors.

The coefficients of Cluster 7 consistently indicate no evidence of impact of lockdown duration on solar installations in both the contemporaneous model without control variables and the following contemporaneous model that includes socioeconomic, demographic, and policy variables. The results for June 2020 to August 2020 are consistent with the previous model without including the socioeconomic, demographic, and policy variables. Except for the base cluster, all the other three clusters, cluster 2, cluster 8, and Cluster 9 of Victoria, as shown in Table 16, signify the resilience of the residential solar market of Victoria by suggesting no effect of active lockdowns across the state on solar installations during this period.

As illustrated in Figure 13Figure 13Figure 13, the number of solar installations experienced a sharp increase in July 2020. Even then, the results provide no evidence of a correlation between lockdown duration and rooftop solar uptake. One possible explanation for no evidence of a negative impact could be the subsequent dip during August, these abrupt fluctuation in trend might be the reason of insignificant results. Despite the disruption in the supply chain of essential solar PV components (56) Since it was the initial phase of the pandemic, retailers might not have depleted their solar panel stocks at that time, and the construction industry remained operational. Furthermore, since this was merely the second lockdown for these areas and the duration of the COVID-19 restrictions was relatively brief, the residential solar adoption decision might not be directly associated with the active lockdown. Another possibility is that the other explanatory variables might have masked the relationship, or the adoption was influenced by the lagged lockdown, which at this stage had a uniform duration for the entire State.

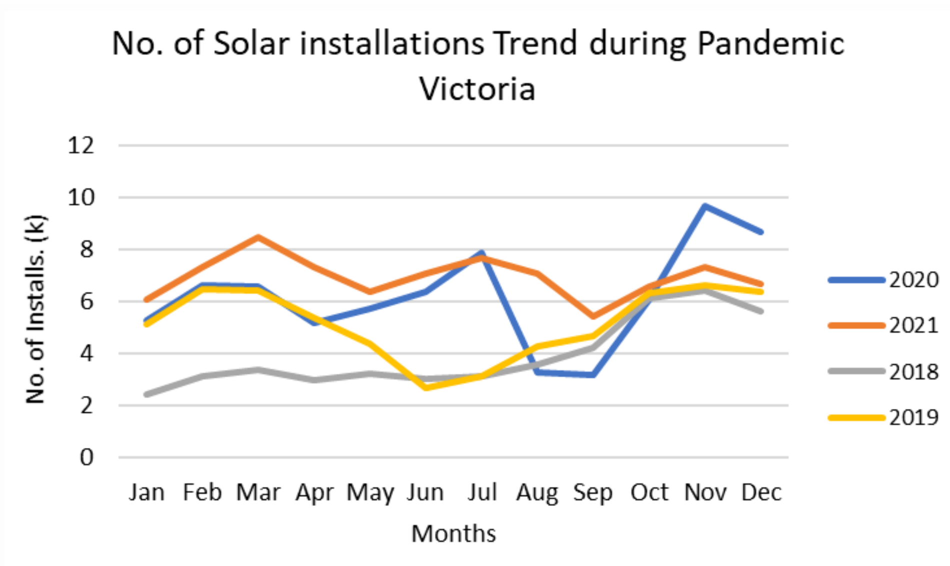

Figure 13. No. of Residential Solar Installations Trend Victoria during and before COVID-19

Victoria was the sole state experiencing a lockdown from September 2020 to November 2020. However, the estimate of Cluster 9 consisting of Melbourne postcodes suggests a negative association of the length of lockdown with the number of residential solar installations indicating that for Melbourne, the increase in the duration of lockdown is correlated with a decline in residential solar adoption during this period. Conversely, the coefficients of Cluster 3, and 4, both include regional Victoria, where Cluster 4 comprises merely eleven postcodes of Mitchell Shire, show no relationship between the extent of lockdown and solar PV uptake in these postcodes, demonstrating regional Victoria residential solar market resilience to active lockdown duration.

Table 24.Results of Contemporaneous model with Control Variables 2021.

	ln number of solar installations Dec 2020 - Mar 2021	ln number of solar installations Apr - Jun 2021	ln number of solar installations Jul - Sep 2021	ln number of solar installations Sep - Nov 2021
	(1)	(2)	(3)	(4)
Age 35 - 54	-0.0557	0.2	1.359*	0.9
Age 55 and over	0.598*	0.391	0.882**	1.363***
Married	-0.789*	-1.376***	-1.083**	-1.191**
Separate houses	-0.578***	-0.465***	-0.0962	-0.387**
University Education	1.085***	0.736**	0.749*	0.992***
High School Education	1.146**	0.785*	1.257**	0.886*
Gender	1.057	4.041***	3.516***	3.866***
Unemployed	1.147	1.596	1.671	-1.23
Household Income	-0.00000292**	-0.00000209*	-0.00000171	-0.00000311**
Number of Bedrooms	0.331***	0.369***	0.182*	0.288***
Number of Children	-0.0464	-0.239*	-0.203	-0.0628
Number of Persons	0.400***	0.422***	0.415***	0.255**
Population	0.0000156***	0.0000155***	0.0000141***	0.0000139***
Owned outright	-0.384	-0.137	-0.540*	-0.518*
Owned with mortgage	0.296	-0.028	-0.137	0.374
SRES Subsidy Zone Rating	0.357**	0.272	0.263	-0.0464
Construction Ban			-0.0331	
Lockdown Duration Cluster 1	0	0	0	0
Lockdown Duration Cluster 2		-0.0756*	0.0346	-0.253***
Lockdown Duration Cluster 3	0.0649	0.0287	0.047	-0.102

Lockdown Duration Cluster 4	0.201		-0.0349	-0.145
Lockdown Duration Cluster 5			-0.0447	-0.109
Lockdown Duration Cluster 6			-0.128	0.0893*
Lockdown Duration Cluster 7			0.153*	0.386***
Lockdown Duration Cluster 8			0.334	-0.178***
Lockdown Duration Cluster 9			0.178	
Lockdown Duration Cluster 10			0.123	
Lockdown Duration Cluster 11				
Lockdown Duration Cluster 12				
Lockdown Duration Cluster 13			0.0186	
Lockdown Duration Cluster 14			-0.118	

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10.*

The period from December 2020 to March 2021 features only two clusters, both located in Sydney's Northern Beaches, with a relatively small sample size of nine postcodes in each cluster. The estimate for Cluster 4 indicates an increase in residential solar uptake as lockdown length increases when regressed without the inclusion of socioeconomic and demographic explanatory variables as shown in *Table 18*. However, there is no evidence of this correlation when these explanatory variables are incorporated. Given the small sample size of the cluster, it is possible that the homogeneous socioeconomic and demographic characteristics of these postcodes are obscuring the impact of lockdown length on the number of solar installations.

The timeframe spanning April to June 2021, similar to September 2020 to November 2020, incorporates only Victoria's single-state clusters. Cluster 2, representing regional Victoria, exhibits a negative relationship between lockdown duration and residential solar adoption during this period, consistent with Table 18 findings, illustrating that longer lockdowns in regional Victoria were associated with higher residential solar adoption. In contrast, Cluster 3, comprising Melbourne postcodes, shows no evidence of an association between the duration of the lockdown and the number of solar installations as shown in *Table 24*. Otherwise, the cluster suggested lockdown duration correlated rise in uptake without including socioeconomic, demographic, and policy variables.

July 2021 to September 2021 was when almost all the States of Australia had paused construction for a different duration and timings around this period, which included residential solar installations. Apart from the initial shutdown of the industry, there were restrictions on on-site capacity and working in an occupied dwelling, affecting the residential solar adoption detrimentally depending on the duration of restrictions. Therefore, the construction ban variable included for this model, as shown in *Table 24*, demonstrates no statistically significant correlation between the length of the construction industry shutdown and the number of solar installations at the confidence level of 10%. As the variable is designed with a range of seven days intervals of construction ban, the pause of a week or two might not have significantly impacted the number of solar installations as suggested by construction ban model results, as shown in Table 25. The estimate of Cluster 3 indicates a statistically significant association between the construction industry shutdown and the number of residential solar installations, which implies that 14 to 20 days of pause lead to an almost 18% decrease in residential solar uptake in Cluster 3. This cluster consists of postcodes of Sydney NSW's western suburbs.

Table 25. Results for Construction Ban Cluster Model.

	ln number of solar installations Jul 21- Sep 21 (1)	**ln number of solar installations Sep 21- Nov 21 (2)**
Age 35 - 54	1.361*	1.230*
Age 55 and over	0.821**	1.441***
	-1.348***	-1.391***
Separate houses	-0.044	-0.343*
University Education	0.927**	0.958***
High School Education	1.499***	1.359***
Gender	3.572***	3.947***
Unemployed	1.252	1.075

Household Income	-0.00000219*	-0.00000123
Number of Bedrooms	0.197*	0.283***
Number of Children	-0.214	-0.0717
Number of Persons	0.429***	0.216**
Population	0.0000144***	0.0000141***
Owned outright	-0.502*	-0.683**
Owned with mortgage	-0.204	0.297
SRES Subsidy Zone Rating	0.0106	0.0225
Lockdown Duration	-0.00433	-0.00152
Construction Ban Cluster 1	0	0
Construction Ban Cluster 2	0.0146	0.109***
Construction Ban Cluster 3	-0.172*	-0.0977
Construction Ban Cluster 4		0.295***

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10.*

Given that the forced shutdown of construction work in Victoria was implemented in September 2021 to October 2021 therefore, to analyse the plausible effect of this shutdown, the same model is used for September 2021 to November 2021 timeframe. Although the coefficient for Cluster 3 comprising of Postcodes of Victoria, the only State that had an active halt on construction work during this timeframe, yields statistically insignificant results, but the line graph, as shown in Figure 13, shows a sharp dip in the number of residential solar installations in September during the forced closure time of the industry.

Furthermore, the other construction bans clusters in this model act as lag variables demonstrating the correlation of lagged duration of the construction ban with the number of residential solar installations. As shown in *Table 24*, lagged length of pause on the construction industry is positively associated for Cluster 2 and 4, with the number of solar installations during this period, suggesting the effect of the construction industry shut down residential solar adoption was temporary and did not last long.

Meanwhile, the results for lockdown duration clusters during July 2021 to September 2021, as shown in *Table 24*, illustrates that the longer lockdown resulted in a 16.5% increase in the number of residential solar installations in Cluster 7 postcodes. Cluster 7 includes mostly regional postcodes of New South Wales, and only fifteen postcodes of regional Victoria, suggesting residential solar adoption in clusters with a greater proportion of regional New South Wales postcodes were positively affected by lockdown length.

Since October was the last month that might have any COVID-19 lockdowns in Australia could be the reason for including the largest number of significant lockdown duration clusters among all timeframes. Clusters 2 and 8 show the extent of the lockdown-correlated decline in the number of residential solar installations in these postcodes. Cluster 8 encompasses Melbourne and suggests a negative impact of lockdown length on residential solar adoption, possibly these postcodes after the end of almost two years of lockdown. The reason might be that people were aware that it was the end of the COVID-19 lockdown; therefore, they did not need to rush for solar PV installations and were less likely to be involved in home upgrading activities.

Conversely, Cluster 6, encompassing regional New South Wales and Cluster 7, comprising postcodes of the Australian Capital Territory, indicate a positive relationship between the extent of lockdown and the number of residential solar installations, suggesting that, unlike Victoria, regional New South Wales and the Australian Capital Territory longer lockdowns have stimulated residential solar uptake where the Australian Capital Territory had the highest positive impact with 47.1% lockdown duration correlated growth in residential solar uptake.

In summary, the length of the lockdown was more likely associated with a drop in the number of residential solar installations for the postcodes of Victoria, with the only positive correlation existing for postcodes of Melbourne from July 2021 to September 2021, the most stringent and the last lockdown of the State. On the other hand, clusters encompassing a higher proportion of the Australian Capital Territory and New South Wales were inclined to the lockdown duration correlated rise in residential solar uptake whenever significant.

In instances where the correlation between the active lockdown duration and residential solar uptake was evident, it indicated varied effect across states. This included curtailing the uptake in Victoria while augmenting in New South Wales and the Australian Capital Territory. However, other states have scarcely any lockdown after the first one and, if implemented they were significantly brief. But these occurrences were not typical; in many cases, no statistically significant association could be found suggesting complexity of the relationship. It might be possible that, depending on their unique socioeconomic and demographic characteristics and policy differences, various regions of the same state may react to lockdown measures in different ways. Correlation between these variables and the active lockdown duration might explain this heterogeneity why, although being in the same state, certain clusters have a strong link with the number of solar installations while others do not.

Over and above the analysis of relationship between the lockdown duration and the number of residential solar installations the socioeconomic, demographic, and Small-scale Renewable Energy Scheme explanatory variables offers insights into the determinants influencing the uptake during the COVID-19 pandemic. Among these variables age, marital status, type of dwelling, education, gender, household income, number of bedrooms, number of children, number of persons, house ownership, and SRES subsidy rating demonstrated significant association with residential solar adoption. Middle age i.e. 35 years to 54 years has association with higher residential solar uptake during July 2021 to September 2021 the most stringent and the second across the country lockdown with a coefficient valued 1.36. As middle age people are more likely to be working and had more social responsibility of children and elderly parents the second lockdown for most of the States and postcodes motivated more middle-aged people to adopt residential solar.

Conversely, in the pandemic, old age has a significant positive impact on residential solar deployment. Since the beginning of the COVID-19 intermittent lockdowns, people aged 54 years and above had a higher preference for adopting residential solar, except for only one period, April 2021 to June 2021. It could be attributed to the fact that older people are less likely to be engaged in physical work, making them more inclined to have work-from-home arrangements. Also, the higher chances of their reliance on pension income might make them more sensitive to electricity bill costs. However, postcodes with a higher share of married couples were less likely to adopt residential solar. This might be due to the COVID-19-driven lockdowns and restrictions associated rise in household expenses from amplified grocery bills, electricity bills, and possibly home-schooling-related needs and the uncertain economic situation during the pandemic. The solar uptake decision as a significant investment for married individuals became more complicated than before and, consequently, had lower uptake among them.

University education had a significant positive relationship with residential solar deployment during these two years of the pandemic. As individuals with university education stand greater chances of having highly paid jobs and work-from-home opportunities, boosting their probability of adopting solar PV. Similar results are evident for high school education, implying postcodes with a higher proportion of people with high school education had a higher number of residential solar installations. The reason might be different for them; for instance, they probably have higher financial stress from increased household bills due to staying home for more prolonged. Future job uncertainty encouraged them to invest the existing capital to save future expenses.

Additionally, females had greater likelihood of installing solar PV during COVID-19. Although COVID-19 was an unprecedented and unparalleled event still, the positive relationship between female and residential solar uptake is consistent with a previous study (114). The variable for unemployment does not hold statistical significance there are chances of collinearity between unemployment and household income or other variables such as level of education might be explaining the same aspect

During the pandemic postcodes greater share of resident of larger dwellings featuring numerous bedrooms had 19.6% to 46% more number of residential solar installations. People living in multiple-bedroom residence mostly have bigger families consequently higher energy bills. Therefore, in order to save their recurring energy expenses, they are more likely to adopt residential solar combined with their ability to afford the upfront cost.

The residential solar deployment decreased among the families with greater number of children during the pandemic. This could be potentially due to the economic uncertainty around this time complicating the investment decision especially for financially constrained families. However, the variable had significant correlation with number of installations for one forth time of the pandemic. Contrary to number of children, number of people had strong positive correlation with solar PV uptake since after the first lockdown with increasing the likelihood by 29% to 54.8% in the postcodes with greater share of larger household size.

Among house ownership, houses owned with mortgage have almost 140% increased uptake before the first lockdown i.e. January 2020 to March 2020. But no evidence of the association of between number of solar installations and house ownership with mortgage is found later during the pandemic.

In addition, the findings of this study suggest significant association of Small-scale renewable energy scheme with residential solar uptake during more than half of the pandemic since the estimates of the SRES zone rating demonstrate strong positive relationship of SRES subsidy zone rating with number of solar installations for January 2020 to March 2021. The residential solar deployment surged almost 181% during the first lockdown to 42.9% during December 2020 to March 2021 period with increase in the subsidy ratings. There could be several potential factors responsible for this change for instance market saturation it is possible that most of the potential consumer have already availed the opportunity and have installed solar PV or the retails may have faced shortage of the solar panels due the supply chain disruption of solar panels and their components. Another possibility is change in consumers behaviour people may have acclimated with new pandemic life efficiently managing their energy expenses consequently less interested in the subsidy.

Moreover, two of the variables type of dwelling i.e. separate houses and house owned outright showed counter-intuitive relationship with residential solar diffusion during the COVID-19, implying decreased number of installations with increased proportion of these factors in postcodes. The potential causes might be collinearity as the occupant of separate houses are mostly have high income, better education, and are more inclined to have children and larger families. Another possible reason could be the relatively short duration of two years than twelve years since the residential solar adoption accelerated or the use of aggregated data based on the nature of study.

8.3 Lag Model

Since the lag days of lockdown for April 2020 to May 2020 was a single thus shows no evidence of impact on number of residential solar installation during this time as shown in *Table 26.Table 26*

Table 26. Results for Lag Model 2020.

	ln number of solar installations Apr - May 2020 (1)	**ln number of solar installations Jun - Aug 2020 (2)**	**ln number of solar installations Sep - Nov 2020 (3)**
Age 35 - 54	0.514	0.858	0.271
Age 55 and over	0.639	0.820**	1.431***
Married	-0.234	-0.413	-0.706
Separate houses	0.142	-0.205	-0.476***
University Education	0.685*	0.475	1.178***
High School Education	1.210**	0.930*	0.642
Gender	3.260***	3.516***	2.103***
Unemployed	4.066*	-0.751	0.521
Household Income	-0.000000529	-0.00000231*	-0.00000386***
Number of Bedrooms	0.0521	0.245**	0.349***
Number of Children	0.0988	-0.259*	-0.181
Number of Persons	0.170*	0.409***	0.419***
Population	0.0000153***	0.0000142***	0.0000133***
Owned outright	-0.598*	-0.825***	-0.591**
Owned with mortgage	0.157	-0.124	0.465*
SRES Subsidy Zone Rating	1.060***	0.682***	0.644***
Construction Ban			
Lagged Lockdown Duration	0	0.00383	-0.00609***

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10.*

The estimate of lagged lockdown duration shows no evidence of significance for June 2020 to August 2020 period suggesting that the first lockdown may not have any strong effect on residential solar deployment. Possibly due to the fact it was the beginning of the unprecedent COVID-19 and it was the first lockdown the impact might be temporary and worn off quickly as shown in **Error! Reference source not found.** the number of installations raised in July but had a drop in August therefore, making it difficult to ascertain significant relationship and isolate it from the other socioeconomic and demographic key influential explanatory variables.

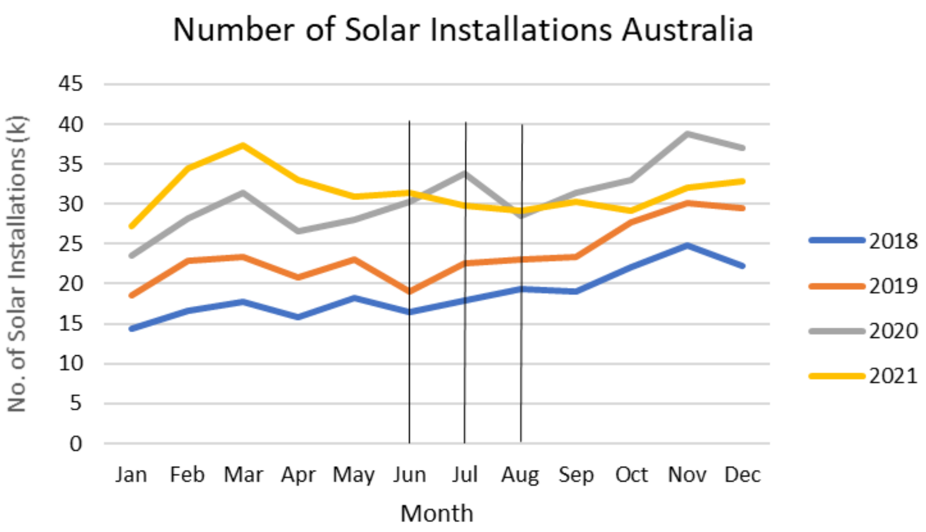

Figure 14. National number of residential solar installations trend before and during COVID-19 pandemic

On the contrary, the accumulative lagged days of lockdown have significantly negative correlation with residential solar diffusion during almost the last quarter of the year indicating the postcodes with longer previous lockdown experienced 0.6% decrease in number of solar installations as shown in *Table 26*. This could be possibly attributed from several reasons including the supply chain disruption of solar panels and their essential parts, COVID-19 driven economic uncertainty prompting individuals to prioritize the essential and immediate needs over long-term investments, reduced income, and increased financial stress.

The same impact is evident for December 2020 to March 2021 timeframe, demonstrating increase in previous lockdowns was associated with approximately 0.12% decline in residential solar deployment as shown in Table 27. The same factors probably would have attributed to this continued negative correlation the disruption of solar panel and its components supply chain and the raised financial uncertainty among the potential residential solar adopters. However, the relatively small coefficient might have implicated the possible adaption of people to the lockdown conditions.

The accumulative lagged days of lockdown illustrates no sign of significant impact on number of residential solar installations from April 2021 to June 2021 period. The lockdowns during December 2020 to March 2021 as shown in *Table 24* were brief with quite small cluster sizes as evident from Table 19, suggesting diminishing effect of previous lagged lockdowns length up until November 2020 on residential solar uptake. The diminishing effect of lagged lockdown duration might be pointing to the adaption of households to the pandemic crisis.

Table 27. Results for Lag Model 2021

	ln number of solar installations Dec 2020 - Mar 2021 (1)	**ln number of solar installations Apr - Jun 2021 (2)**	**ln number of solar installations Jul - Sep 2021 (3)**	**ln number of solar installations Sep - Nov 2021 (4)**
Age 35 - 54	-0.101	0.265	1.396*	0.893
Age 55 and over	0.638*	0.441	0.791**	1.821***
Married	-0.888*	-1.388***	-1.106**	-1.345***
Separate houses	-0.589***	-0.487***	0.0152	-0.536***
University Education	1.092***	0.731*	0.918**	1.199***
High School Education	1.091**	0.819*	1.587***	1.086**
Gender	1.067	4.022***	3.519***	3.664***
Unemployed	0.848	2.32	2.191	-0.17
Household Income	-0.00000269**	-0.00000193	-0.00000201*	-0.00000198
Number of Bedrooms	0.318***	0.374***	0.179*	0.259***
Number of Children	-0.063	-0.232*	-0.172	-0.0724
Number of Persons	0.428***	0.433***	0.360***	0.396***
Population	0.0000158***	0.0000154***	0.0000136***	0.0000152***
Owned outright	-0.335	-0.193	-0.590**	-0.778***
Owned with mortgage	0.323	-0.0448	-0.187	0.520*
SRES Subsidy Zone Rating	0.0855	0.366*	0.315	0.11
Construction Ban			-0.0626*	

Lagged Lockdown Duration	-0.00118**	0.000462	0.00121**	-0.00100***

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10.*

The accumulative lagged length of lockdown points to significantly positive association with growth of residential solar diffusion from July 2021 to September 2021. The coefficient suggests that for every additional day of previous lockdown, there was a 0.12% surge in the number of residential solar installations during this time. More than a yearlong restrictions and sporadic lockdowns might have changed household behaviour to the COVID-19 shock and people got adapted with new pandemic lifestyle, along with several COVID-19 associated financial support policies by government people might have started to make long-term investment to cope with the pandemic driven high energy bills.

The coefficient of Construction ban variables signifies 6.5% decline in the uptake due to the forced shut down of the construction industry in the given timespan which was not evident in previous contemporaneous model as shown in *Table 24*.

By the end of the pandemic from September 2021 to November 2021 the residential solar deployment was dropped 0.1% with per day increased in preceding days of lockdown. A plausible reason for this could be the extended lockdown fatigue or might be weather related the weather during September to November is more pleasant affecting the energy bills less. Therefore, the potential consumer may have been less interested in solar uptake during this time as the government also had announced the roadmap to end almost two year-long intermittent lockdowns.

While the lag model indicates more significant relationships of past lockdown length with residential solar deployment during the pandemic, the nature of the relationship was not consistent. There was a change from negative during the last period of 2020 (i.e. September 2020 to November 2020) to positive during July 2021 to September 2021, which was the longest and one of the most stringent lockdowns for New South Wales and Victoria, with diminishing effect meanwhile. Nevertheless, the lagged days of lockdown was associated with a drop in the number of solar installations for September 2021 to November 2021. Two possible reasons include seasonal changes due to change of weather or lockdown fatigue stimulating people to move back to the pre-pandemic norm of life. However, on the other side it is possible that the underlying cause of these change in association might stem from the interaction of socioeconomic, demographic, and policy variables with the lag days of lockdown. They could be the potential moderators that may have an impact on the correlation between the length of past lockdowns and the number of residential solar installations. For instance, a prolonged lockdown may have a less severe negative impact on solar installations in locations with greater income levels, indicating that income may have a moderating effect on the impact of lockout duration on solar installations.

8.4 Contemporaneous Interaction model

Given that there was a single day lockdown on 31st March 2020 this timespan was not included in this model. Among the strongest plausible interaction of extent of lockdown with the socioeconomic and demographic variable is separate houses influencing the residential solar deployment since after the first lockdown as shown in *Table 28* and Table 29, suggesting the varied effect of extent of lockdown on residential solar adoption in postcodes with greater share of separate house compared to those with lower proportion. This could potentially stem from their tendencies to have higher energy bills especially during the lockdowns increasing the energy consumption substantially equipped with larger roof spaces make the investment in solar PV more attractive.

University education conversely was associated with decrease in uptake in postcodes with longer lockdowns. As shown in *Table 28* and Table 29, people with university education were approximately 59.4% to 5.5% less likely to adopt residential solar in postcodes with higher number of days of lockdown than people without university education. The variable showed evident correlation after the first lockdown period and from April 2021 to September 2021. This might be due these people may not only be associated with job security issue but also, they could have jobs that are more vulnerable to the economic slumps caused by the pandemic, for instance academia, technology, or corporate sectors. Consequently, making them reluctant to large investments like residential solar in postcodes. Another reason could be people with university education might also have better information and awareness of future long-term economic impact of these extended lockdowns and hence, motivating them to focus more on immediate needs and savings than investments.

Positive strong combined impact of lockdown length and the proportion of bedrooms in a dwelling on the number of solar installations is evident as shown in *Table 28* and Table 29, suggesting among the postcodes with longer lockdowns people living in dwellings with greater number of bedrooms were more inclined to uptake residential solar. Extended lockdowns leading to higher energy consumption hence, the bills stimulate these individuals to invest in residential solar more than other. Likewise, almost 3.8% to 18% higher solar deployment have been observed in postcodes with lengthier lockdowns larger household sizes. Greater number of people potentially result in higher energy consumptions especially in time of lockdown spending most of the time at home and might also have more financial resources since number of children is kept separate in this study.

Table 28. Results for Contemporaneous Interaction Model 2020

	ln number of solar installations Apr - May 2020 (1)	**ln number of solar installations Jun - Aug 2020 (2)**	**ln number of solar installations Sep - Nov 2020 (3)**
Lockdown Duration*Age35to54			
Lockdown Duration*Age54andover			0.157***
Lockdown Duration*Married			0.196*
Lockdown Duration*Separate houses		0.0640**	0.0589***
Lockdown Duration*University Education		-0.141**	
Lockdown Duration*High School Education			
Lockdown Duration*Female	1.011*		
Lockdown Duration*Unemployed	4.402**		
Lockdown Duration*Income		-0.000000527*	
Lockdown Duration*Number of Bedrooms		0.0322**	
Lockdown Duration*Number of Children	-0.232**	0.102*	
Lockdown Duration*Number of Persons		0.0382*	
Lockdown Duration*Owned Outright	-0.277*		
Lockdown Duration*Owned with Mortgage			
Lockdown Duration*Zone Rating			

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Only the interactions terms mentioned in the table.*

The interaction between houses that owned outright and the lockdown length indicated significant association with number of solar installations. However, as shown in *Table 28* and Table 29, the interaction demonstrates varying direction of the relationship. During the first lockdown, the association was negative indicating, longer lockdown was correlated with 31.9% decreased probability of solar adoption in postcodes with greater share of homes that are owned outright. It might possibly be attributed to these residents have more financial security and less need of energy cost-saving during this period.

The significant positive relationship from July 2021 to November 2021, illustrates lengthier lockdown was correlated with a rise in number of solar installations in postcodes with greater share of dwellings that were owned outright. This could be because staying home for longer time might have raised energy cost due to higher consumption of energy and their capacity to afford solar installation upfront cost made them more likely to adopt solar.

Similarly, the home that owned with mortgage were more inclined to adopt residential solar when experienced extended lockdowns from April 2021 to September 2021 timeframe where during April 2021 to June 2021 for each added lockdown day, almost 77.7% the number of residential solar installations rise in the postcodes with higher proportion of homes that were owned with a mortgage. Perhaps a year-long restrictions and intermittent lockdowns might have driven people to invest is residential solar to reduce their plausible heightened lockdown associated energy bills during this time.

The relative smaller, yet significant, estimate for the July 2021 - September 2021 timespan suggests that continued effect, but at a diminished rate, into the later period. Considering July 2021 to September 2021 had some additional influential factors at the same time including the forced shut down of construction industry hindering the ability of these households to adopt solar during this time. Furthermore, the government's release of a COVID-19 recovery roadmap during this period, signalling the eventual end of lockdowns, could have shifted people's priorities. Instead of focusing on home improvements, such as solar panel installations, homeowners might have turned their attention towards preparing for a return to normal life. The relief and anticipation associated with the easing of restrictions could have fostered a desire to engage in outdoor activities, travel, and social interactions, rather than investing in home upgrades.

Table 29. Results for Contemporaneous Interaction Model 2021

	ln number of solar installations Apr - Jun 2021 (1)	**ln number of solar installations Jul - Sep 2021 (2)**	**ln number of solar installations Sep - Nov 2021 (3)**
Lockdown Duration*Age35to54			
Lockdown Duration*Age54andover			
Lockdown Duration*Married			0.250**
Lockdown Duration*Separate houses	0.274***	0.0367**	0.0422*
Lockdown Duration*University Education	-0.466**	-0.0531*	
Lockdown Duration*High School Education	1.100**		
Lockdown Duration*Female			
Lockdown Duration*Unemployed			-1.875**

Lockdown Duration*Income			
Lockdown Duration*Number of Bedrooms	0.141***		0.0338**
Lockdown Duration*Number of Children			
Lockdown Duration*Number of Persons	0.165***		0.0369**
Lockdown Duration*Owned Outright		0.0829*	0.120*
Lockdown Duration*Owned with Mortgage	0.575***	0.0557*	
Lockdown Duration*Zone Rating			0.171***

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10%. Only the interactions terms mentioned in the table.*

The households with higher number of children were less likely to install residential solar in postcodes that stayed in lockdown for longer. A plausible reason for this could be the additional financial and time commitments associated with raising children, perhaps further amplified during lockdown. These households might be more concerned for immediate needs, remote schooling, and entertainment to keep the kids busy thus, have fewer financial resources and attention for long-term investments like solar panel installations.

The positive correlation for post first lockdown period, on the other hand, could suggest comprehension of heightened energy costs due to more time spent at home with children, which could prompt some households to invest in solar energy to control their energy bills. Another potential reason could be the more comprehensive and larger sample size for this period given that the first lockdown was the only nation-wide one whereas, subsequent lockdowns were more localized primarily affecting particular cities or States. This nationwide lockdown might have apprehended a more diverse range of experiences and behaviours, thereby leading to more robust and representative findings.

The interaction term Lockdown Duration*Unemployed showing a positive coefficient for first lockdown, whereas, a negative during September 2021 to November 2021 i.e. part of the last lockdown and the end of the pandemic suggests that the relationship between the lockdown duration and the residential solar deployment in postcodes with higher unemployment rates varies over time. This could possibly be attributed to several government financial support policies during the pandemic including COVID-19 disaster payments, Job keeper payment, and mortgage payment deferral schemes. Which after gradual reduction ended by the end of September 2021. Consequently, they might have prioritized securing employment over making investments for energy-cost saving.

The significant positive estimate of interaction between lockdown duration and being married during September 2020 to November 2021 and September 2021 to November 2021 i.e. the same month for both years might illustrates a seasonal trend in the residential solar deployment. This could potential stem from several reasons for instance these months may coincide with the time when households typically plan their finances for the following year therefore, may be more likely to make significant investments, such as solar installations, during this period especially in the course of the longer lockdowns. Another reason could be the weather conditions as married couples more likely to have financial stability might have more probability of adopting solar ahead of summer to save the additional cost of air conditioning where extended lockdowns might have elevated their energy bills even more.

Nevertheless, the interaction term for age, household gross income, gender, and high school education have significant coefficients for short time periods. The interaction term between lockdown duration and income is significant and negative for post first lockdown period. Increased energy bills due to lockdown-induced changes in consumption were likely not a major concern for high-income households. Amid the economic uncertainties brought on by the pandemic, these households may have opted to delay their decisions regarding solar adoption. The brief duration of this significant relationship could be attributed to the same reasons. Furthermore, the inclusion of data from across Australia might have led to more robust results, thereby reducing the period during which this relationship was significant.

Similarly, everyday increase in lockdown in postcodes with higher proportion of older people boosted almost 20% of their chances of adopting residential solar from September 2020 to November 2020. A plausible reason for this could be the end of the year often brings about significant financial decisions for many individuals. For elderly people, this time period might align with end-of-year financial planning or budgeting, motivating them to install solar for summer onset with lockdowns knowing that they could be spending more time at homes.

Analogous are the results for high school education as the interaction between extent of lockdown and high school education shows strong positive association with solar uptake during April 2021 to June 2021. This could potentially stem from a yearlong pandemic restrictions and longer lockdowns in these postcodes might have motivated these individuals to take control over the energy bills for the onset of extreme cold weather of winters. Also, later was the most stringent lockdown or pandemic restrictions period of the nation could be the reason of loss of significance in this interaction. Therefore, the diminishing significance of the interaction term might illustrate these additional barriers faced by the high school education demographic during the more stringent lockdowns.

Lastly, higher SRES subsidy ratings boost approximately 18.6% residential solar diffusion in postcodes that experience lengthier lockdowns. Given that this was the time when Australia was gradually transitioning towards the end of pandemic restrictions this transition might also signify the end of immediate economic uncertainty for many households. With restrictions easing and businesses reopening, there would be a prospect of economic recovery and increased financial stability. This could lead to households being more willing and able to invest in solar installations, especially in regions with higher solar irradiance associated with higher subsidy rates.

8.5 Lag Interaction model

The same variable has interaction for longer periods with the lagged days of lockdown as have with contemporaneous days of lockdown whereas, the difference is the persistent association of these interactions over these periods.

Among the strongest and most persistent interactions is between the lagged lockdown duration and separate houses for a year from September 2020 to September 2021 as shown in *Table 30* and *Table 31*, suggesting a sustained relationship between these variables throughout this period. The potential reasons include the lockdown-induced increased energy consumption raising the energy bills with the availability of roof spaces and finance for solar installation upfront cost every additional day of previous lockdown amplified the 0.35% to 0.7% likelihood of the residential solar uptake in postcodes with greater share of separate houses.

A yearlong negative significance of the interaction between lagged lockdown length and university education suggests that for individuals with university education, longer periods of past lockdowns are correlated with a decline in the number of residential solar installations. As mentioned earlier job insecurity and economic uncertainty might stimulated people to focus more on the essentials rather than investment in solar installation. It is also possible that these individuals have anticipated the post-lockdown resumption therefore, considering these lockdowns as temporary measures they might have considered to delay the solar investment decision.

From September 2020 to September 2021 the tendency of residential solar diffusion in the postcodes with larger proportion of multi bedrooms dwellings surge 0.1% to 0.27% with increase in the length of past lockdown. There might be several reasons associated with this trend. Among which could be the plausible larger size of the multi bedroom resident resulting in spiked electricity cost due to staying home for longer time thus prompting these households to adopt residential solar to save their energy costs. Additional, spacious domiciles might have more financial resources increasing their likelihood to install solar. The consistent significance of this interaction for extended time periods suggests that this trend remained stable over the year.

Table 30. Results for Lagged Interaction Model 2020

	ln number of solar installations Jun - Aug 2020 (1)	ln number of solar installations Sep - Nov 2020 (2)
Lagged Lockdown Duration*age35to54		
Lagged Lockdown Duration*age54andover		0.0181**
Lagged Lockdown Duration*Married		
Lagged Lockdown Duration*Separate houses		0.00712**
Lagged Lockdown Duration*University Education		-0.0187***
Lagged Lockdown Duration*High School Education		
Lagged Lockdown Duration*Female	0.249***	
Lagged Lockdown Duration*Unemployed		-0.273***
Lagged Lockdown Duration*Income		
Lagged Lockdown Duration*Number of Bedrooms		
Lagged Lockdown Duration*Number of Children		
Lagged Lockdown Duration*Number of Persons		
Lagged Lockdown Duration*Owned Outright		
Lagged Lockdown Duration*Owned with Mortgage	0.0355*	
Lagged Lockdown Duration*Zone Rating	0.0604*	0.0276***

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10%. Only the interactions terms mentioned in the table.*

This interaction term for lagged lockdown duration and number of persons in a household is indicative of the effect of a lockdown's length on the decision to install solar panels, with the number of persons serving as a proxy for household size. The positive significance as shown in *Table 30* and *Table 31*, suggests that as the increase in number of persons in a household, also increases the positive impact of past lockdown duration on solar adoption. This could potentially stem from the need of these households to manage their energy costs due to the heightened bills higher energy induced by longer past lockdowns. Given that these households inclined to have higher income level might have surged the uptake in these postcodes.

However, a yearlong consistent significance of this interaction for reflects the ongoing influence of lockdown experiences on household behaviours and decisions. Unlike contemporaneous interaction, accumulative lagged lockdown duration has strong positive interaction with SRES subsidy zone influencing the residential solar deployment for a year from June 2020 to June 2021, indicating the effectiveness of SRES thus, making the Australian residential solar market resilient during the pandemic.

This could be due to a couple of reasons. Firstly, in areas with higher solar irradiance, the potential benefits and savings from solar energy are more apparent, which could encourage solar adoption especially during and after periods of lockdown where energy use might be higher. Secondly, areas with higher zone ratings also receive more substantial subsidies, which could make solar adoption more financially attractive. The significance of this interaction over multiple periods indicates that these factors have a lasting effect on how past lockdown experiences influence solar adoption decisions.

Table 31.Results for Lagged Interaction Model 2021

	ln number of solar installations Dec 2020 - Mar 2021 (1)	**ln number of solar installations Apr - Jun 2021 (2)**	**ln number of solar installations Jul - Sep 2021 (3)**	**ln number of solar installations Sep - Nov 2021 (4)**
Lagged Lockdown Duration*age35to54				
Lagged Lockdown Duration*age54andover				
Lagged Lockdown Duration*Married				0.00951*
Lagged Lockdown Duration*Separate houses	0.00353**	0.00569***	0.00424***	
Lagged Lockdown Duration*University Education	-0.00730*	-0.0120***	-0.00783**	
Lagged Lockdown Duration*High School Education				
Lagged Lockdown Duration*Female				
Lagged Lockdown Duration*Unemployed				
Lagged Lockdown Duration*Income		-3.26e-08**	-2.95e-08**	

Lagged Lockdown Duration*Number of Bedrooms	0.00191*	0.00265***	0.00202**	0.00112*
Lagged Lockdown Duration*Number of Children	0.00518*	0.00630**		
Lagged Lockdown Duration*Number of Persons	0.00257**	0.00335***	0.00248**	0.00163**
Lagged Lockdown Duration*Owned Outright				
Lagged Lockdown Duration*Owned with Mortgage		0.0100***	0.00639**	
Lagged Lockdown Duration*Zone Rating	0.00925*	0.0109**		

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10%. Only the interactions terms mentioned in the table.*

The interaction between past lockdown duration and dwellings that are owned with mortgage is significant for longer time than its interaction with active lockdown duration however, indicates the upsurge in positive correlation of solar uptake with house ownership with mortgage with increased in lagged lockdown length for the same period as for active lockdown duration with an additional timespan of post first lockdown. This could be attributed to several factors as mentioned previously.

Contrary to the interaction with active lockdown length, houses that are owned outright and high school education demonstrates no variation in solar adoption in correlation with past lockdowns. Moreover, number of children unlike its interaction with active days of lockdown imply consistent strong positive interaction with passed days of lockdown, but for first half of 2021 instead of 2020 suggesting persistent lockdowns might have motivated households with more children to adopt solar due to the continued home-schooling and increased home stay induced rise of energy cost. Delayed decision due to additional financial and family commitments could be another possible explanation.

Gender and aged over 54 years suggest consistent results with contemporaneous interaction model. Unemployment on the other hand signify negative interaction with accumulative lagged lockdown length and for almost the last quarter of 2020. Additionally, marital status illustrates strong interaction for fewer timespans but still positive. Whereas, income still shows negative correlation but for longer period and even smaller coefficient than for active lockdown indicating higher household income postcodes were less inclined to uptake residential solar with everyday increase in past lockdown.

Given the unprecedented circumstances of the COVID-19 pandemic, our study reveals a noteworthy shift in the residential solar adoption landscape. Contrary to prior research that typically associated older individuals with lower interest in solar PV adoption (288) (289) (25), our findings indicate that, during the pandemic, older demographics displayed increased interest in investing in residential solar systems. This shift may be attributed to the rising energy costs, which made older individuals, often on fixed incomes, more vulnerable to higher utility bills. Simultaneously, they might have had greater financial resources to cover the upfront costs of solar PV installation, along with available roof space for installations.

In contrast, our research indicates that individuals with both high school and university-level education were more inclined to adopt solar panels during the pandemic. However, it is crucial to contextualize our findings within the existing literature, which has yielded mixed results concerning the relationship between education and solar uptake. While some studies align with our results, suggesting that less educated individuals have shown an increased interest in solar adoption in recent years (95) (290), others propose that solar adopters tend to be highly educated 'innovators' in PV technology demonstrating that non-adopters primarily consist of individuals with a medium level of education (291). These varying outcomes emphasize the intricate interplay of factors in the renewable energy adoption landscape. External events such as the COVID-19 pandemic can introduce unique dynamics and alter demographic profiles within the solar PV market.

Additionally, our analysis highlights that the number of bedrooms, family size, and gender continued to exhibit consistent patterns during the pandemic, mirroring trends observed in prior studies. Postcodes with larger households, more extensive family sizes, and female-headed households exhibited a higher ratio of solar adopters compared to other areas (292) (81) (114) (293).

Moreover, in the event of another pandemic, it is advisable for governments to contemplate the implementation of localized lockdowns. Also, authorities should carefully deliberate whether to impose a prohibition on the construction industry, while also considering the possibility of exempting solar installations from such restrictions. This exemption can be justified by the fact that solar installation activities can be conducted in compliance with physical distancing measures, without necessitating interaction with residents.

Chapter 9: Conclusions

This study assesses and comprehends the effect of the COVID-19 pandemic on the Australian residential solar market, aiming to determine how the COVID-19 lockdowns duration affected the growth of residential solar installations at various pandemic stages. Since the literature indicates a strong relationship between the socioeconomic and demographic variables and the solar uptake decision, the study aims to analyse the lockdown duration associated effect of these variables on the individual's residential solar uptake decision during the pandemic emphasis.

The rooftop solar adoption growth trend is identified by employing the contemporaneous model without control variables. However, another contemporaneous model with control variables is included to scrutinize the lockdown duration effect. This model is utilized for examining the direct effect of the lockdown length. The delayed effect, on the other hand, is investigated by the lag model. Moreover, taking the short-term and intermittent aspects of lockdowns into account, their effect is studied using short analysis periods following the timespan the lockdowns were implemented in the corresponding postcodes and ensuing the change in adoption trend. The lockdown duration correlated determinants of solar adoption during the pandemic are identified by integrating distinct interaction models for active lockdown duration associated and lag lockdown duration correlation, apart from the key socioeconomic and demographic influencing factors of residential solar adoption from the literature, including age, marital status, gender, population, number of bedrooms, level of education, types of dwelling, and number of persons. The model entailed the number of children, house ownership with a mortgage, and a house owned outright due to their pertinence to the research question.

The empirical findings suggest a diverse state-specific effect of active lockdown duration contingent upon the number of lockdowns implemented. Based on the results, New South Wales and the Australian Capital Territory postcodes with longer active lockdowns showed significant growth in residential solar adoption across a particular analysis period. On the other hand, postcodes of Victoria indicated depletion in the number of installations in correlation with active lockdown length. Since the variable to estimate the impact of lag lockdown duration is continuous instead of categorical, thus implicating national-level aggregate results. The estimate suggests a more sustained correlation of solar adoption with the lag length of lockdown; however, likewise, with the active lockdown duration, the relationship is heterogeneous. This variation in the nature of the association could be attributed to the socioeconomic and demographic factors affecting the adoption directly and in association with lockdown duration that might be stimulating or impeding the adoption during the pandemic.

9.1 Barriers to Residential Solar Adoption

The correlation between lockout duration and solar uptake is dependent on the level of education of the individuals in a postcode, especially the university level, negatively affecting the uptake in correlation with active lockdown duration by **0.466** during the **April 2021 to June 2021** period by **0.141** during **June 2020 to August 2020**, and **0.0531** during **July 2021 to September 2021** as shown in Table 29. Since the results suggest a significant coefficient for interaction between the university education and the lockdown duration with a more persistent year-long negative association from **September 2020 to September 2021** with the value ranging from **0.00730 to 0.0187 (0.7% - 1.9%)** as shown in Table 30 and Table 31, past lockdown duration indicates a stable and enduring correlation between university education and lockdown duration. This persistent significance across consecutive periods indicates a consistent correlation between these variables suggesting the correlation is not temporal or spontaneous, but rather denotes a persistent, constant association. This continuous significance can point to a persistent impact of one variable on the other, underscoring the significance of taking this interaction effect into account in our comprehension and interpretation of the larger context suggesting the vulnerability of this socioeconomic group regarding residential solar deployment. The negative association of this group across multiple periods with active and past lockdown duration indicates their increased likelihood to delay or rethink significant investments, like the installation of solar panels, during times of economic volatility and uncertainty. But more investigation is required to pinpoint the precise causes of this apparent susceptibility.

Regarding lockdown length association, unemployment was another deterrent to residential solar uptake and had a negative influence on the uptake, with a value of **1.85** from **September 2021 to November 2021**, the almost end of the pandemic in correlation with active lockdown duration while **0.273** during **September 2020 to November 2020** in correlation with past lockdown duration. Uptake among this socioeconomic group increased during first lockdown probably owing to reduce their heightened energy costs. However, ongoing or even worsening financial struggles may have discouraged people from adopting solar in this group due to the persistent lockdowns, they may have had to give priority to more pressing financial requirements. Such financial impediments to solar adoption among the unemployed may persist as we move forwards into the post-COVID era.

Apart from lockdown related barriers to solar uptake, significant negative influences with high coefficient values ranging from **0.866 to 1.376** from the marriage variable suggests that married households might have been less likely to install solar power during the study period. This could be linked to a number of things, possibly including the distinct financial goals that married couples have, including property ownership or family-related expenses. In contrast, the dynamics of decision-making in married households may result in a slower or more cautious approaches to the adoption of new technologies, such as solar power. This highlights the necessity of devising policy that can efficiently target and involve this particular demographic, consequently stimulate the diffusion of residential solar in time ahead. Alternatively, the negative coefficient for the marriage variable in the study period might be due to higher solar uptake in the past, leaving a larger pool of unmarried households as potential solar installers in the study period.

9.2 Key Determinants of Residential Solar Adoption

The results from the interaction models suggest one of the key driving factors of solar uptake in correlation with the active and past lockdown duration was separate houses significantly increasing the deployment in postcodes with longer active lockdowns with **0.0367 to 0.274** estimate value while boosting in postcodes with lengthier past lockdown by **0.35% to 0.71%**. Detached residencies have greater tendency to adopt residential solar due to the availability of roof space. However, the physical distancing opportunity exhibited by these dwellings might have facilitated the installation process during the lockdowns and pandemic. Living in larger homes with greater number of bedrooms was another stimulating factor for individuals to install residential solar in postcodes with extended active and past lockdowns. The socioeconomic characteristic has raised the number of installations with a **0.141** coefficient value in postcodes with lengthier active lockdowns from **April 2021 to June 2021** analysis period while increasing the adoption during other periods and among postcodes with extended past lockdowns. Significant lifestyle adjustments brought about by the pandemic, such as a rise in work-from-home or flexible working and increased home stay habits, have boosted domestic energy use. Some of these modifications might continue after the pandemic, further incentivizing households to choose solar power.

The choice to switch to solar energy during the lockdown may have long-lasting effects on the market because solar systems are frequently long-term investments. Larger-home owners who learned about the financial and environmental advantages of solar energy during lockdown would continue to use it more frequently. There was correlation to increased solar uptake in the contemporaneous cross-section model.

The long-lasting modifications in household dynamics and energy consumption induced by the pandemic might be responsible for the persistent influence of household size on solar uptake, which may continue post-pandemic. Given that the number of person variable has been significantly associated with almost **0.4** by coefficient increased residential solar diffusion during **most of the pandemic** across Australia. The variable was also associated with solar diffusion growth in correlation with contemporaneous and lag lockdown length. For instance, the pandemic may have reshaped the work pattern, leading to an increase in remote employment, which would continue to drive up domestic energy demand even after the lockdown restrictions are relaxed. Additionally, the pandemic might have increased awareness of the value of sustainability and self-sufficiency in bigger households, promoting the continued use of solar energy systems. It follows that the size of a household, as a motivating factor for solar adoption, is expected to continue determining Australia's residential solar market in the post-pandemic future.

The positive correlation of house ownership with mortgage and lockdown durations in both models implies that mortgage-holding homes are more likely to install solar systems both during and after lengthier lockdown periods, with a coefficient value reaching **0.575** high during **April 2021 to June 2021** period, as shown in Table 29. Furthermore, the evidence of significant association of this group with increased residential solar uptake in the contemporaneous model with control variables demonstrates its influence on the uptake. One motivating factor might be individuals who are financially constrained with long term commitments are more likely to look for ways to lower their monthly spending. The ability to lower energy expenses offered by installing a solar system makes it a desirable investment for this group. The potential for continuous work-from-home arrangement could result in higher residential energy usage, supporting the financial case for solar adoption among mortgage-holding homeowners. Additionally, a greater understanding of the environmental benefits of residential solar over using fossil fuel-generated electricity may encourage these homeowners to uptake residential solar and contribute towards the climate change needed since this group could not have property rights constraints facing tenants also might be less financially constrained, therefore, have more potential to uptake residential solar.

The decline in number of solar installations among the families with more children during the first lockdown might stem from their heightened family responsibilities and economic uncertainty. The trend on the other hand changed as the lockdowns proceeded, as people may have begun to proactively plan to have more time at home with increased domestic activities. This may have stimulated these families to install solar to control their energy bills. This trend might continue post-pandemic due to the change in people’s lifestyle after COVID-19 as spending more time at home with more home-based activities could be a new normal. Solar adoption among homes with more children may be significantly influenced by the possibility for increased energy independence and cost savings. However, it's also crucial to study additional variables that could have an impact on this association, such as parental education levels, income levels, and the ages of the children, among others. These factors may contribute to a more thorough knowledge of how the number of children in a home affects various factors.

The SRES subsidy zone rating positive correlation with lockdown durations implies a rise in number of solar installations in regions with longer lockdowns and greater subsidy during and following lockdown periods. The contemporaneous model results align with this finding, demonstrating a positive relationship between zone rating and solar system uptake for almost a year of the pandemic with escalating the adoption by **1.034** estimate value during the **first lockdown**, suggesting heightened energy cost and economic uncertainty induced by the pandemic stimulated people to take advantage of the greater subsidy offered by the government to save their monthly expenses. This positive relationship highlights the significance of subsidy on solar deployment therefore, implying that upfront cost of solar installation might be a dominant barrier for many potential consumers.

During almost the whole pandemic there was a positive link from the female variable to solar uptake, as suggested by the results from the contemporaneous model. This could potentially be attributed to the fact that women exhibit a greater sensitivity towards environmental concerns, possess a preference for energy self-sufficiency, or are influenced by various economic and social factors. Energy independence preferences induced by the pandemic might last. Additionally, if the pandemic has changed gender roles or attitudes that influence solar adoption decisions in any way, this effect may continue.

Nevertheless, a more comprehensive analysis of the pandemic links with socioeconomic and demographic aspects, especially those related to women's perspective on residential solar adoption, is necessary before making any conclusive predictions. Hence, this emphasises the necessity of further study in this field to comprehend the mechanisms promoting solar adoption in the post-pandemic era.

On the hand, high school education was another motivating factor for solar adoption during the pandemic as indicated by the persistent evidence of its significance in the contemporaneous model with control variables as shown in Table 23 and *Table 24*. Nevertheless, it significantly correlated with active lockdown duration with a **1.011** substantial estimate value. However, the association was only for the **first lockdown** and no significant association with past lockdown duration, suggesting individuals with high school level education are more prone to adopt residential solar in the time of financial uncertainty and job insecurity as apart from energy bill saving the financial incentives in the form of feed-in-tariff might have attracted more of the individuals from this demographic group. This indicates its possible continuous association with adoption.

The results showed evidence of continuous correlation between individuals age and residential solar deployment during the pandemic however, the relationship with lockdown durations both active and lagged was occasional. This indicates that the number of residential solar installations was significantly accelerated by people aged 54 and older. The trend is likely to continue after the pandemic as this group looks to have more potential to acknowledge and undertake the long-term economic and environmental benefits of solar technology because they are often homeowners, more financially stable, and more mindful of household energy expenses. As a result, this older age group might continue to play a crucial role in expanding the residential solar market of Australia.

9.3 Policy Implications

University level education may have been a positive impact (284) in the past, but then other groups are catching up during this period like older age, dedicated awareness programs to target these demographic groups might increase the uptake. Individuals with university education have better education therefore they might respond well to climate change and sustainability aimed educational programs however, older people might need additional and more comprehensive information of the financial benefits of solar uptake and the potential assistance available for them.

In addition, financial incentives including subsidized loans, competitive Feed-in-Tariff, and Tax credits might promote solar adoption among the individuals with larger household size especially the ones with more children and bigger dwellings as these potential socioeconomic groups are financially more constrained and need to save their energy bills more. However, since the residents of dwellings that are owned with mortgage have more tendency to adopt residential solar therefore, providing them with subsidized loan based on their mortgage repayments for solar installations might boost the diffusion in this group.

As indicated by the results, older people particularly those who are aged 54 and over had higher uptake during pandemic therefore. Considering them as the prospective prosumer, dedicated solar rebates programs for them across Australia could be useful, as offered by New South Wales some people aged over 54 are eligible for this Rebate swap for solar scheme. Apart from being a receiver of a low-income household scheme, the resident of New South Wales must have either a valid Pensioner Concession Card or a Department of Veterans Affairs Gold Card and be the house owner. The recipient will then receive the rebate from the rebate swap for the solar scheme under its terms and conditions instead of low-income households. This might increase the solar diffusion in other states of the country as well like Victoria where the lockdown duration correlated with declines in residential solar uptake. However, like New South Wales solar rebates for low income households should also be introduced in other states as this program will be able to boost the uptake not only among the low-income households but also among the unemployed individuals.

The results suggest the efficacy of SRES. However, the SRES does not take equity/inequality into account because there are no means of testing involved. Replacing capacity-based subsidy rates with income-based subsidies may enhance the equity of the scheme, thereby promoting greater uptake among low-income households. As indicated by our results, postcodes of some states where the construction industry was put on hold for two or more weeks experienced a decline in the residential solar uptake suggesting that in case of a recurrence of lockdowns in the future, policymakers can consider whether construction bans are a good idea. Since the residential solar installation could be done without interaction with the household resident mostly, therefore, excluding it from the construction ban might overcome this temporal barrier without risking public health.

A tax deduction policy for residential solar prosumers might also boost the adoption. As the ATO introduced rules for claiming tax deductions for 'working from home expenses' since the pandemic, such as for increased electricity consumption from the grid, a similar policy for the households which install solar panels might interest individuals with employment or higher income.

9.4 Study limitations

Due to the nature of the study, which requires analysing the key influential variables of residential solar adoptions at a particular time, i.e. the pandemic cross-section study is the suitable methodology. However, many types of cross-sectional approaches exist, including the Poisson model (236) and zero-inflated negative binomial (118). Still, they are less relevant for this study since Australian postcodes have many solar installations in contrast to some areas in Belgium and the United States, which did not have many or any solar installations (partly because the studies were done 5-10 years ago).

The use of aggregated data to determine the plausible impact of COVID-19 on the residential solar market of Australia might be the principal limitation of the study as the data facilitated the model to suggest a comprehensive synopsis of the impact; however, it was unable to capture the details regarding the causes of the plausible barriers and determinants of the uptake during the pandemic. It's possible that certain unobserved factors that would have been responsible for the trend of solar PV diffusion during the pandemic were overlooked in this study. Any future post-pandemic changes in governmental policies for residential solar that could have a substantial impact on the diffusion is beyond the scope of this study.

Moreover, some detailed studies on the prospect of some potential prosumers of residential solar including women, individuals with university level education, and married couples need to be investigated in more detail to understand their attitude towards solar uptake. Similarly, as the relationship of gross household income and residential solar adoption during the pandemic was significant with very small coefficient, further research into this relationship is needed to fully understand the uptake behaviour of different household income groups regarding solar deployment.

This study used the cross-section model, which is unable to incorporate policies like 'First home buyers' and others that are the same across the postcodes. Future studies, using a panel econometric approach which assesses changes over time, can investigate how solar uptake changed when the first home buyers' scheme (or other policies) were introduced or changed. There is some rationale for expecting an effect related to housing transactions, as more new homes might lead to more solar panels, as people might be more likely to put solar panels on a new house.

Instead of longitudinal analysis, specifically incorporated into a panel regression, which is preferred for establishing causal identification cross-section regression model is used for this study. The panel regression method provides a higher level of confidence in the regression coefficients' ability to identify causal relationships rather than correlations which are proxies for other unobserved effects, but cross-sections can include many more important and interesting variables which are not available over time. Furthermore, our study is designed for postcode-level data, which, as aggregated data, is more comprehensive as compared to household-level data acquired from surveys, but there can be area-level correlations that give some unexpected results in most aggregated studies. Also, a short time period is used for analysis in this study which might be ideal for direct lockdown impacts as the lockdowns across Australia were short, temporary, and sporadic, while a longer time horizon would give a better indication of possible changes following the pandemic.

9.5 Suggestion to enhance the Australian solar energy business after the pandemic

9.5.1 Energy market stability

For the energy market during the COVID-19 pandemic, one of the most critical factors to directly impact the world energy market was the sudden decline in the consumer demand for existing oil stock. Considering this as an opportunity, some electricity generation plants placed gigantic crude oil orders at lower market prices and built new storage facilities. In the later months, this situation created massive uncertainty in the energy market for some countries as they were left with a few options to either buy the oil at a higher price or delay orders. At present, it is crucial to assure the investment of stockholders in flexibility by flexible investments and clear pathways for it, believing investments are not for immediate rewards but long-standing. In this regard, the government could emphasise the investors about the stock market stability of the solar energy business in the light of long-term stability that could sustain their trust and stock market money in the solar energy business.

9.5.2 Collaboration between real estate and solar energy business

In Australia, the solar cell program and business have been majorly focused on the houses, and the percentage of the building having solar system insulated are relatively quite small. In this regard, there is a big gap between real estate and solar energy businesses due to which the small number of apartment buildings that have a solar system installed. A building has multiple stories, and apartments and its electricity demand are higher than a single house depending upon the number of people living in a building. As the solar electricity FiTs are less in dollar value than buying the electricity from the grid, there is a vast potential to install a PV system on the buildings to supply electricity, especially during the off-peak hours when solar electricity production is maximum. A solar system could be workable for a building with 10-15 apartments if tenants/ residents could be given convincing information when leasing or buying the condo. As storage battery cost is a significant factor for single families living in a home, this could be made affordable for buildings with several apartments and more families residing in the building. In this regard, a framework of a small amount of recurring payment included in the fortnightly rent or bond money in return for solar electricity and reduced electricity bills could help the building management cover the cost of batteries and the overall solar system. In addition, the Australian government has plans to construct and develop many new suburbs. The architect of these new houses or buildings could have built-in structures for solar systems installations, thus reducing the installation cost of the rooftop PV panels. As constructing new suburbs for the growing population necessitates the installation of grid electricity lines, which could be tricky and expensive for remote locations, the government could make smart suburbs that could run solely on solar energy. In this way, instead of spending billions of dollars to supply grid electricity to remote locations, these expenditures could be turned into solar business investments that may indirectly enhance the solar business and solve the energy demands in remote areas in Australia. In addition, the cost of the batteries or the overall solar system could be added to the initial mortgage values with some financial schemes similar to the extended pay-off period. Collaboration of established real estate and solar businesses could be a good starting point to expand the solar energy business.

9.5.3 Enhancing solar energy business by innovative advertisement

For most people, a solar energy system is thought of as a means of gaining cheaper electricity or reducing their monthly/yearly electricity bills. In this regard, consumer gets information about the solar system from word of mouth, looking at the rooftop of an existing solar system of the surroundings or some broadcast media advertisement. Additionally, some studies have been performed to link the solar uptake with education in a region; however, these investigations possess disagreement. In this regard, the missing factor is the amount of information that people acquire from social media. Social media is a mandatory part of our lives, enhancing our sources of information and inclination towards a specific project. We need to educate people by launching a national social media campaign in Australia to encourage consumers and investors about the solar energy business. In parallel with convincing people on dollar savings using solar energy, a paramount emphasis on reducing the drastic effect of increased carbon emission and global warming should be laid. Significantly, the harsh effects of the recent bushfire in Australia have had major impacts on lives and cost billions of dollars to the Australian economy; the benefits of utilising solar energy should be taught at every level of primary, high school and university level with a similar emphasis as planting new trees. In this scenario, educating people through social media could be vital in educating people about the benefits of utilising solar energy and may significantly influence people's understanding of the genuine need for solar energy. These social media campaigns would benefit a clean environment, fulfil energy needs, and help enlarge the solar energy business in Australia.

9.5.4 Analysing solar electricity data to predict people's behaviour during a pandemic situation

As the repeated lockdowns in Australia forced people to stay home, a shift in the energy demands from the industry to the residential sector occurred as more people tended to stay or work from home. Monitoring the electricity usage data could be an indicator of people's social behaviour, lifestyle, and work aptitudes during a pandemic. Additionally, solar electricity production is maximum during the daytime, where extra electricity is fed into the grid. A reduction in its amount could be affected and monitor the people's response to the lockdown enforcement. Therefore, a critical analysis of the solar electricity produced during the lockdown situation is essential and valuable to prepare for the next unforeseen pandemic.

9.6 Opportunities for future research

In addition to the overall initial investment cost to purchase and install the solar energy system, the major problem of utilising solar energy to produce electricity soars because of its limited operationality; generate solar electricity during the daytime only and store into batteries for evening peak consumption, the prerequisite requirement of availability of large area for panel installation, and dependency of governmental regulations or incentives for the solar energy market. Electricity storage systems such as batteries, with extended lifespan, are significantly costly than solar cells. Sunlight-dependent solar electricity production costs are different from traditional power station electricity production costs. Presently, electricity production and storage system are considered unconditionally only for remote regions and facilities where other opportunities to supply electricity through the grid are unavailable or have tremendous costs.

Moreover, as this energy sector relies on governmental enticements, it may be affected significantly during any governmental crisis. For example, the solar energy market was drastically affected by the collapse of the US mortgage market in 2007, which adversely affected the prices of solar panels and other electronic equipment (294). This crisis made it challenging for the solar equipment manufacturing companies to increase their capital by liquidating more shares, resulting in the fall of solar stock prices. At this point, the solar energy market instigated a significant conflict among the crisis analysing experts and policymakers who could not come to definite conclusions to introduce newer policies to uplift the solar market during or after this crisis. Despite these limitations, one should consider that the solar energy market still has great potential due to continuing scientific advancement, which will decrease the initial investment cost and extend the bandwidth of solar energy use and help make the earth environment greener for our future generations.

Appendix

Table 32. Results of COVID Clusters residential solar installations during 2020

	ln number of solar installations Jan - Mar 2020	ln number of solar installations Apr - May 2020	ln number of solar installations Jun - Aug 2020	ln number of solar installations Sep - Nov 2020
	(1)	(2)	(3)	(4)
ln average installations for 2018 & 2019 January - March	0.975***			
	(0.023)			
Number of cases in March 2020	735.7			
	(1446)			
COVID Cluster 1	0.258	0.223	0.34	0.647**
	(0.191)	(0.165)	(0.214)	(0.245)
COVID Cluster 2	0.359**	0.677***	0.500***	0.674***
	(0.11)	(0.12)	(0.15)	(0.178)
COVID Cluster 3	0.0223	0.0228	0.16	0.204*
	(0.099)	(0.115)	(0.119)	(0.103)
COVID Cluster 4	0.365***	0.265***	0.449***	0.565***
	(0.07)	(0.076)	(0.063)	(0.059)
COVID Cluster 5	0.403***	0.275**	0.407***	0.227***
	(0.103)	(0.094)	(0.083)	(0.068)
COVID Cluster 6	0.402***	0.448***	0.148	0.386**
	(0.102)	(0.126)	(0.165)	(0.128)
COVID Cluster 7	0.0256	0.154	0.251*	0.0982
	(0.118)	(0.09)	(0.107)	(0.086)
COVID Cluster 8	0.163	0.295*	0.176	0.166
	(0.233)	(0.144)	(0.149)	(0.146)
COVID Cluster 9	0.0728	0.0176	-0.139	0.0748
	(0.094)	(0.093)	(0.083)	(0.077)
COVID Cluster 10	0	0	0	0
	(.)	(.)	(.)	(.)
ln average installations for 2018 & 2019 April - May		0.907***		
		(0.026)		
Number of cases during April - May 2020		798		
		(3498.4)		
ln average installations for 2018 & 2019 June - August			0.976***	

			(0.024)	
Number of cases during June - August 2020			9330.8	
			(5087.2)	
ln average installations for 2018 & 2019 September - November				0.989***
				(0.02)
Number of cases during September - November 2020				-3687.0*
				(1580.9)
Number of observations	556	542	574	570
R^2	0.817	0.802	0.846	0.87

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Also, standard errors are mentioned in the parentheses.*

Table 33. Results of COVID Clusters residential solar installations during 2021

	ln number of solar installations Jan - Mar 2021	ln number of solar installations Apr - Jun 2021	ln number of solar installations Jun - Aug 2021	ln number of solar installations Sep - Nov 2021
	(1)	(2)	(3)	(4)
ln average installations for 2018 & 2019 January - March	0.936***			
	(0.025)			
Number of cases during January - March 2021	5708.8			
	(8171.2)			
COVID Cluster 1	0.535***	0.532***	0.279**	0.698*
	(0.129)	(0.087)	(0.105)	(0.274)
COVID Cluster 2	0.394**	0.637***	0.463*	0.671***
	(0.13)	(0.097)	(0.222)	(0.14)
COVID Cluster 3	0.384***	0.347**	0.115	0.321**
	(0.078)	(0.116)	(0.109)	(0.113)
COVID Cluster 4	0.704***	0.545***	0.195*	0.648***
	(0.068)	(0.07)	(0.081)	(0.067)
COVID Cluster 5	0.461***	0.386***	0.266***	0.382***
	(0.1)	(0.09)	(0.077)	(0.079)
COVID Cluster 6	0.321**	0.386**	0.385***	0.461**
	(0.105)	(0.128)	(0.098)	(0.141)
COVID Cluster 7	0.187	0.149	0.231*	0.303***
	(0.108)	(0.101)	(0.092)	(0.077)
COVID Cluster 8	0.0933	0.0128	0.235	-0.0582
	(0.2)	(0.144)	(0.187)	(0.142)

COVID Cluster 9	0.0239	-0.035	-0.119	0.0579
	(0.107)	(0.086)	(0.099)	(0.095)
COVID Cluster 10	0	0	0	0
	(.)	(.)	(.)	(.)
ln average installations for 2018 & 2019 April - June		0.920***		
		(0.022)		
Number of cases during April - June 2021		-4461.5		
		(7008.6)		
ln average installations for 2018 & 2019 July - September			0.905***	
			(0.026)	
Number of cases during July - September 2021			273.3	
			(189.3)	
ln average installations for 2018 & 2019 September - November				0.936***
				(0.022)
Number of cases during September - November 2021				103.1
Number of observations	563	569	568	566
R^2	0.822	0.817	0.81	0.838

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Also, standard errors are mentioned in the parentheses.*

Table 34. Results of residential solar installations during 2020

	ln number of solar installations Jan – Mar 2020	ln number of solar installations Apr – May 2020	ln number of solar installations Jun – Aug 2020	ln number of solar installations Sep – Nov 2020
	(1)	(2)	(3)	(4)
ln average installations for 2018 & 2019 January – March	0.706***			

	(0.039)			
Number of cases in March 2020	-893			
	(1394.2)			
SRES Subsidy Zone	0.07	0.0725	0.0639	-0.0216
	(0.17)	(0.135)	(0.126)	(0.12)
Age 35 – 54	-0.0837	-0.0311	0.0432	0.000944
	(0.069)	(0.07)	(0.066)	(0.066)
Age 55 and over	-0.00909	0.0995	0.0325	-0.0131
	(0.075)	(0.074)	(0.071)	(0.072)
Gender	0.193**	0.146**	0.113*	0.0904
	(0.059)	(0.056)	(0.054)	(0.053)
University Education	0.0949	0.0691	0.00889	0.0838
	(0.064)	(0.065)	(0.06)	(0.057)
High-School Education	0.0958	0.0263	-0.161*	-0.0198
	(0.074)	(0.073)	(0.075)	(0.063)
Low income households	-0.0652	-0.0631	-0.0813	0.0336
	(0.06)	(0.059)	(0.059)	(0.055)
Middle income households	0.0126	0.0547	0.033	0.0714
	(0.081)	(0.073)	(0.08)	(0.066)
High income household	-0.0538	-0.0263	-0.0371	-0.0587
	(0.07)	(0.075)	(0.064)	(0.063)
Married	-0.0528	0.0451	0.0269	0.0152
	(0.065)	(0.062)	(0.057)	(0.058)
One or less bedrooms household	-0.144*	-0.108	-0.0445	-0.00493
	(0.067)	(0.065)	(0.067)	(0.057)
Two bedrooms household	0.00994	0.119	-0.013	-0.0522
	(0.061)	(0.066)	(0.057)	(0.056)
Three or more bedrooms household	0.248**	0.213**	0.0513	0.182**
	(0.077)	(0.075)	(0.07)	(0.068)
Owners	-0.0738	-0.0727	-0.022	-0.0192
	(0.072)	(0.067)	(0.063)	(0.058)

Owners with mortgage	0.0694	0.0137	-0.0632	-0.0123
	(0.074)	(0.077)	(0.072)	(0.071)
Separate houses	0.0311	0.0915	0.00531	-0.0901
	(0.09)	(0.063)	(0.058)	(0.062)
Duplexes	-0.051	0.0395	0.0168	-0.0149
	(0.073)	(0.059)	(0.048)	(0.051)
Two or less persons household	-0.333***	-0.188**	-0.316***	-0.202**
	(0.071)	(0.07)	(0.061)	(0.064)
Six persons household	-0.163*	-0.0432	-0.0123	-0.0481
	(0.073)	(0.081)	(0.07)	(0.065)
Four persons household	-0.162	0.0225	0.0717	0.0233
	(0.119)	(0.142)	(0.103)	(0.112)
Eight or more persons household	0.123*	0.0984	0.155**	0.147*
	(0.062)	(0.07)	(0.06)	(0.058)
Population	0.0000138***	0.0000126***	0.0000100***	0.0000109***
	-0.00000225	-0.00000263	-0.00000195	-0.00000216
One child family	0.16	-0.0772	0.114	-0.056
	(0.088)	(0.083)	(0.075)	(0.07)
Two children family	0.155	0.134	0.103	0.087
	(0.116)	(0.144)	(0.1)	(0.098)
Three or more children family	-0.0571	-0.0386	-0.0507	-0.0738
	(0.084)	(0.08)	(0.082)	(0.065)
COVID Cluster 1	-0.19	-0.129	0.053	0.429
	(0.225)	(0.181)	(0.229)	(0.262)
COVID Cluster 2	-0.0938	0.325*	0.0838	0.370*
	(0.141)	(0.16)	(0.173)	(0.187)
COVID Cluster 3	-0.444***	-0.236	-0.164	-0.0682
	(0.119)	(0.128)	(0.123)	(0.119)
COVID Cluster 4	-0.109	-0.00619	0.0792	0.302**
	(0.112)	(0.109)	(0.11)	(0.093)
COVID Cluster 5	0.115	0.106	0.149	0.124

	(0.104)	(0.1)	(0.098)	(0.077)
COVID Cluster 6	0.117	0.326*	0.0785	0.284*
	(0.142)	(0.15)	(0.154)	(0.143)
COVID Cluster 7	0.0505	0.162	0.250*	0.124
	(0.109)	(0.088)	(0.106)	(0.097)
COVID Cluster 8	0.156	0.293*	0.192	0.151
	(0.185)	(0.127)	(0.14)	(0.139)
COVID Cluster 9	0.0612	-0.00265	-0.149	0.0644
	(0.091)	(0.088)	(0.085)	(0.074)
COVID Cluster 10	0	0	0	0
	(.)	(.)	(.)	(.)
ln average installations for 2018 & 2019 April – May		0.690***		
		(0.047)		
Number of cases during April – May 2020		-506.9		
		(3749.8)		
ln average installations for 2018 & 2019 June – August			0.774***	
			(0.039)	
Number of cases during June – August 2020			5571.3	
			(5703.5)	
ln average installations for 2018 & 2019 September – November				0.795***
				(0.036)
Number of cases during September – November 2020				-5564.5**
				(1972.6)
Number of observations	553	538	570	566
R^2	0.855	0.831	0.869	0.883

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Also, standard errors are mentioned in the parentheses.*

Table 35. Results of residential solar installations during 2021

	ln number of solar installations Jan - Mar 2021	ln number of solar installations Apr - Jun 2021	ln number of solar installations Jul - Aug 2021	ln number of solar installations Sep - Nov 2021
	(1)	(2)	(3)	(4)
ln average installations for 2018 & 2019 January - March	0.635***			
	(0.044)			
Number of cases during January - March 2021	-829.4			
	(8146.3)			
SRES Subsidy Zone	0.319*	0.0921	-0.0534	0.440**
	(0.153)	(0.116)	(0.165)	(0.143)
Age 35 - 54	-0.0273	-0.108	0.0695	-0.0878
	(0.068)	(0.065)	(0.073)	(0.072)
Age 55 and over	0.0815	0.0324	0.0892	0.0397
	(0.084)	(0.07)	(0.072)	(0.075)
Gender	0.0467	0.0326	0.101	0.224***
	(0.049)	(0.049)	(0.058)	(0.053)
University Education	0.0913	0.0781	0.117	0.143*
	(0.067)	(0.059)	(0.062)	(0.058)
High-School Education	-0.0917	0.078	-0.0749	-0.0388
	(0.081)	(0.075)	(0.073)	(0.068)
Low income households	0.013	-0.05	-0.0333	0.0509
	(0.065)	(0.058)	(0.059)	(0.058)
Middle income households	0.0965	0.058	-0.0363	0.00735
	(0.077)	(0.071)	(0.086)	(0.07)
High income household	0.00905	-0.132	-0.0788	-0.103
	(0.066)	(0.068)	(0.064)	(0.069)
Married	0.0432	0.137*	0.0772	0.0835
	(0.058)	(0.062)	(0.063)	(0.062)
One or less bedrooms household	-0.0665	-0.0665	-0.0324	-0.0984
	(0.06)	(0.06)	(0.063)	(0.066)
Two bedrooms household	0.028	0.0573	-0.0133	-0.0974

	(0.067)	(0.062)	(0.058)	(0.056)
Three or more bedrooms household	0.275***	0.0403	0.0763	-0.0509
	(0.081)	(0.069)	(0.072)	(0.072)
Owners	-0.0889	-0.172**	-0.0638	-0.00729
	(0.074)	(0.064)	(0.069)	(0.067)
Owners with mortgage	-0.078	-0.07	-0.111	-0.00932
	(0.067)	(0.069)	(0.065)	(0.067)
Separate houses	0.0329	-0.00828	-0.115	-0.0424
	(0.069)	(0.073)	(0.07)	(0.061)
Duplexes	-0.0484	0.0864	0.000665	-0.00927
	(0.061)	(0.06)	(0.06)	(0.059)
Two or less persons household	-0.459***	-0.297***	-0.272***	-0.266***
	(0.071)	(0.066)	(0.073)	(0.067)
Six persons household	-0.144	0.0588	-0.101	0.0226
	(0.089)	(0.07)	(0.074)	(0.064)
Four persons household	-0.00299	-0.187	-0.029	0.104
	(0.097)	(0.108)	(0.109)	(0.116)
Eight or more persons household	0.144*	0.0625	0.181**	0.0852
	(0.064)	(0.059)	(0.059)	(0.059)
Population	0.0000174***	0.0000142***	0.0000127***	0.0000125***
	(0.)	(0.)	(0.)	(0.)
One child family	0.0401	0.0941	0.0195	0.0496
	(0.085)	(0.076)	(0.078)	(0.082)
Two children family	0.153	0.219*	0.267**	0.0792
	(0.091)	(0.101)	(0.099)	(0.12)
Three or more children family	0.0524	0.133	0.0124	0.00185
	(0.087)	(0.071)	(0.074)	(0.062)
COVID Cluster 1	0.282	0.148	-0.176	0.301
	(0.15)	(0.117)	(0.152)	(0.268)
COVID Cluster 2	0.108	0.0615	-0.179	0.16
	(0.146)	(0.138)	(0.244)	(0.161)
COVID Cluster 3	0.0337	-0.18	-0.416**	-0.0694
	(0.113)	(0.122)	(0.133)	(0.129)
COVID Cluster 4	0.316**	0.0387	-0.323**	0.213*
	(0.112)	(0.097)	(0.122)	(0.105)
COVID Cluster 5	0.221*	0.193*	-0.0167	0.162
	(0.102)	(0.092)	(0.094)	(0.092)
COVID Cluster 6	0.292*	0.157	0.178	0.332*
	(0.129)	(0.151)	(0.117)	(0.152)
COVID Cluster 7	0.240**	0.109	0.217*	0.284***
	(0.092)	(0.096)	(0.088)	(0.076)

COVID Cluster 8	0.175	0.0093	0.175	0.0412
	(0.145)	(0.135)	(0.164)	(0.144)
COVID Cluster 9	-0.0187	-0.0346	-0.142	-0.0106
	(0.1)	(0.081)	(0.09)	(0.082)
COVID Cluster 10	0	0	0	0
	(.)	(.)	(.)	(.)
ln average installations for 2018 & 2019 April - June		0.701***		
		(0.035)		
Number of cases during April - June 2021		-10424.3*		
		(4807.6)		
ln average installations for 2018 & 2019 July - September			0.705***	
			(0.041)	
Number of cases during July - September 2021			248.1	
			(193.9)	
ln average installations for 2018 & 2019 September - November				0.720***
				(0.039)
Number of cases during September - November 2021				170.3
				(118.6)
Number of observations	559	565	564	563
R^2	0.872	0.857	0.851	0.869

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Also, standard errors are mentioned in the parentheses.*

Table 36.0 Results of interaction of COVID-19 lockdown variable with socioeconomic and demographic variables during the first lockdown 2020

	ln number of solar installations April - May 2020			
	(1)	(2)	(3)	(4)
ln average installations for 2018 & 2019 April - May	0.700***	0.704***	0.697***	0.684***
	(0.045)	(0.044)	(0.045)	(0.046)
Number of cases during April - May 2020	-1418.9	-1706.2	-950.8	-1125.6
	(4205.8)	(3981.6)	(3957.)	(3979.6)
SRES Subsidy Zone	0.027	0.0196	0.00418	0.0252
	(0.135)	(0.135)	(0.136)	(0.137)

Age 35 - 54	-0.0279	-0.375**	-0.0288	-0.0281
	(0.069)	(0.142)	(0.069)	(0.068)
Age 55 and over	0.0688	0.0749	0.0754	0.0589
	(0.072)	(0.073)	(0.073)	(0.073)
Gender	-0.138	0.155**	0.143*	0.160**
	(0.129)	(0.056)	(0.055)	(0.055)
University Education	0.0601	0.1	-0.227	0.0882
	(0.068)	(0.066)	(0.161)	(0.064)
High-School Education	0.0154	0.0127	0.00942	0.00964
	(0.071)	(0.07)	(0.071)	(0.07)
Low income households	-0.0566	-0.0485	-0.0484	-0.0353
	(0.061)	(0.06)	(0.061)	(0.061)
Middle income households	0.0598	0.0589	0.054	0.0773
	(0.072)	(0.071)	(0.072)	(0.071)
High income household	-0.0221	-0.0265	-0.0169	-0.0294
	(0.072)	(0.073)	(0.072)	(0.072)
Married	0.0514	0.0702	0.0643	0.0666
	(0.061)	(0.061)	(0.061)	(0.06)
One or less bedrooms household	-0.111	-0.116	-0.119	-0.107
	(0.065)	(0.064)	(0.064)	(0.065)
Two bedrooms household	0.103	0.135*	0.123	0.130*
	(0.064)	(0.064)	(0.064)	(0.064)
Three or more bedrooms household	0.184*	0.209**	0.197**	0.196**
	(0.075)	(0.075)	(0.075)	(0.075)
Owners	-0.0383	-0.0526	-0.0456	-0.0522
	(0.067)	(0.068)	(0.067)	(0.067)
Owners with mortgage	0.0617	0.0459	0.049	0.0497
	(0.076)	(0.075)	(0.075)	(0.075)
Separate houses	0.0674	0.0744	0.0712	0.445**
	(0.062)	(0.063)	(0.063)	(0.156)
Duplexes	0.0428	0.037	0.0446	0.0458
	(0.059)	(0.06)	(0.06)	(0.06)
Two or less persons household	-0.162*	-0.163*	-0.166*	-0.182*
	(0.07)	(0.07)	(0.07)	(0.071)
Six persons household	-0.0437	-0.0521	-0.0425	-0.0292
	(0.079)	(0.08)	(0.08)	(0.08)
Four persons household	-0.00779	-0.00278	0.00228	-0.00178
	(0.143)	(0.138)	(0.142)	(0.139)
Eight or more persons household	0.0973	0.111	0.104	0.11
	(0.068)	(0.069)	(0.069)	(0.069)
Population	0.0000115***	0.0000117***	0.0000114***	0.0000119***
	(0.)	(0.)	(0.)	(0.)
One child family	-0.0777	-0.0717	-0.0751	-0.083

	(0.081)	(0.081)	(0.082)	(0.08)
Two children family	0.148	0.113	0.119	0.139
	(0.148)	(0.14)	(0.146)	(0.144)
Three or more children family	-0.0495	-0.0296	-0.0413	-0.0458
	(0.077)	(0.078)	(0.077)	(0.078)
COVID*Gender	0.0449*			
	(0.02)			
COVID	-0.0214	-0.0224	-0.0213	0.0309
	(0.02)	(0.016)	(0.018)	(0.017)
COVID*Age 35 - 54		0.0508*		
		(0.022)		
COVID*University Education			0.0467*	
			(0.022)	
COVID*Separate houses				-0.0540**
				(0.02)
Number of observations	538	538	538	538
R^2	0.825	0.825	0.824	0.825

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Also, standard errors are mentioned in the parentheses.*

Table 37. Results of interaction of COVID-19 lockdown variable with socioeconomic and demographic variables after first lockdown 2020

	ln number of solar installations June - August 2020				
	(1)	(2)	(3)	(4)	(5)
ln average installations for 2018 & 2019 June - August	0.789***	0.781***	0.776***	0.780***	0.772***
	(0.038)	(0.039)	(0.039)	(0.039)	(0.038)
Number of cases during June - August 2020	6386.3	5331.7	7107.5	2978.3	6126.6
	(5687.5)	(5851.6)	(5849.1)	(5811.6)	(5420.6)
SRES Subsidy Zone	0.0168	0.0085	0.0286	-0.00912	0.0183
	(0.124)	(0.125)	(0.124)	(0.128)	(0.124)
Age 35 - 54	-0.364*	0.034	0.0282	0.0401	0.0437
	(0.148)	(0.066)	(0.067)	(0.067)	(0.067)
Age 55 and over	0.023	0.0202	0.0114	0.024	-0.0026
	(0.069)	(0.069)	(0.07)	(0.069)	(0.064)
Gender	0.105*	0.0919	0.102	0.107*	0.1
	(0.053)	(0.053)	(0.053)	(0.054)	(0.052)
University Education	0.0349	-0.335*	0.0229	0.0281	0.0195
	(0.059)	(0.147)	(0.059)	(0.058)	(0.056)

High-School Education	-0.201**	-0.196**	-0.193**	-0.197**	-0.215**
	(0.069)	(0.069)	(0.069)	(0.07)	(0.068)
Low income households	-0.0555	-0.0562	-0.0507	-0.0512	-0.0515
	(0.059)	(0.059)	(0.059)	(0.058)	(0.058)
Middle income households	0.0103	0.0102	0.0327	0.0243	0.0501
	(0.078)	(0.078)	(0.078)	(0.079)	(0.08)
High income household	-0.0453	-0.0365	-0.0386	-0.0135	0.0217
	(0.064)	(0.063)	(0.064)	(0.065)	(0.065)
Married	0.0682	0.0639	0.0605	0.0641	0.0409
	(0.057)	(0.056)	(0.056)	(0.056)	(0.054)
One or less bedrooms household	-0.0735	-0.0808	-0.0725	-0.0854	
	(0.063)	(0.063)	(0.064)	(0.061)	
Two bedrooms household	0.0069	-0.00831	-0.00234	0.000462	
	(0.057)	(0.057)	(0.057)	(0.057)	
Three or more bedrooms household	0.0448	0.0293	0.0342	0.00728	
	(0.07)	(0.071)	(0.071)	(0.069)	
Owners	-0.012	-0.0042	-0.00941	-0.0248	
	(0.062)	(0.063)	(0.063)	(0.061)	
Owners with mortgage	-0.0469	-0.0462	-0.0478	-0.0306	-0.0655
	(0.069)	(0.07)	(0.07)	(0.071)	(0.066)
Separate houses	-0.00954	-0.017	0.259	-0.0168	-0.013
	(0.059)	(0.058)	(0.142)	(0.057)	(0.054)
Duplexes	0.00088	0.00741	0.00643	0.0135	0.0137
	(0.049)	(0.049)	(0.049)	(0.049)	(0.048)
Two or less persons household	-0.291***	-0.297***	-0.306***	-0.296***	-0.307***
	(0.063)	(0.063)	(0.064)	(0.064)	(0.062)
Six persons household	0.0134	0.0245	0.0312	0.00721	0.00873
	(0.071)	(0.073)	(0.073)	(0.068)	(0.072)
Four persons household	0.0625	0.0643	0.0555	0.146*	0.0482
	(0.098)	(0.097)	(0.097)	(0.071)	(0.097)
Eight or more persons household	0.164**	0.161**	0.165**	0.184**	0.154**
	(0.058)	(0.059)	(0.059)	(0.058)	(0.058)
Population	0.00000978***	0.00000945***	0.00000977***	0.00000997***	0.0000105***

	(0.)	(0.)	(0.)	(0.)	(0.)
One child family	0.146*	0.136	0.132		0.124
	(0.073)	(0.074)	(0.074)		(0.073)
Two children family	0.0754	0.0839	0.109		0.127
	(0.095)	(0.096)	(0.095)		(0.095)
Three or more children family	-0.0639	-0.0746	-0.08		-0.0979
	(0.08)	(0.081)	(0.081)		(0.081)
COVID*Age 35 - 54	0.0577**				
	(0.019)				
COVID	-0.0430*	-0.0421*	0.00641	0.00806	0.0183
	(0.018)	(0.018)	(0.015)	(0.016)	(0.017)
COVID*University Education		0.0525**			
		(0.02)			
COVID*Separate houses			-0.0394*		
			(0.018)		
COVID*Number of children				-0.0571**	
				(0.018)	
Number of children				0.344**	
				(0.115)	
Number of bedrooms					0.496***
					(0.13)
COVID*Number of bedrooms					-0.0575**
					(0.017)
Number of observations	570	570	570	570	570
R^2	0.866	0.865	0.864	0.865	0.866

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Also, standard errors are mentioned in the parentheses.*

Table 38. Results of interaction of COVID-19 lockdown variable with socioeconomic and demographic variables between September to November 2020

	ln number of solar installations September - November 2020		
	(1)	(2)	(3)
ln average installations for 2018 & 2019 September - November	0.775***	0.794***	0.792***
	(0.036)	(0.034)	(0.034)

Number of cases during September - November 2020	-6588.1***	-7269.0***	-6164.2**
	(1887.9)	(1731.8)	(1863.4)
SRES Subsidy Zone	-0.0241	-0.0389	-0.0278
	(0.118)	(0.124)	(0.122)
Age 35 - 54	0.0149	0.00144	0.0199
	(0.066)	(0.069)	(0.068)
Age 55 and over	-0.019	-0.000165	-0.0274
	(0.068)	(0.07)	(0.065)
Gender	0.106*	0.0978	0.0959
	(0.053)	(0.052)	(0.052)
University Education	0.0816	0.0965	0.0812
	(0.055)	(0.054)	(0.052)
High-School Education	0.0136	-0.00291	-0.0137
	(0.059)	(0.058)	(0.059)
Low income households	0.0705	0.0569	0.0736
	(0.054)	(0.054)	(0.055)
Middle income households	0.0539	0.023	0.0615
	(0.064)	(0.065)	(0.066)
High income household	-0.0726	-0.0544	-0.0019
	(0.061)	(0.062)	(0.061)
Married	0.0466	0.0388	0.0259
	(0.055)	(0.054)	(0.054)
One or less bedrooms household	0.0138	0.0103	
	(0.054)	(0.055)	
Two bedrooms household	-0.0502	-0.0538	
	(0.055)	(0.057)	
Three or more bedrooms household	0.150*	0.140*	
	(0.066)	(0.064)	
Owners	-0.00763	-0.0188	
	(0.058)	(0.059)	
Owners with mortgage	0.018	0.0119	0.0278
	(0.071)	(0.07)	(0.068)
Separate houses	0.285	-0.103	-0.105
	(0.153)	(0.062)	(0.059)
COVID*Separate houses	-0.0560**		
	(0.02)		
Duplexes	-0.0195	-0.0152	-0.0227
	(0.051)	(0.052)	(0.051)
Two or less persons household	-0.215**	-0.186**	-0.207**
	(0.067)	(0.066)	(0.065)
Six persons household	-0.0217	-0.06	-0.0317

	(0.065)	(0.063)	(0.063)
Four persons household	0.067	0.0736	0.0664
	(0.11)	(0.078)	(0.112)
Eight or more persons household	0.185***	0.178**	0.172**
	(0.055)	(0.056)	(0.055)
Population	0.0000111***	0.0000109***	0.0000110***
	(0.)	(0.)	(0.)
One child family	-0.039		-0.0496
	(0.07)		(0.069)
Two children family	0.0595		0.0804
	(0.096)		(0.095)
Three or more children family	-0.0644		-0.077
	(0.066)		(0.066)
COVID	0.00367	-0.00683	0.00886
	(0.014)	(0.016)	(0.015)
COVID*Number of children		-0.0325*	
		(0.016)	
Number of children		0.208	
		(0.116)	
Number of bedrooms			0.531***
			(0.14)
COVID*Number of bedrooms			-0.0594**
			(0.019)
Number of observations	566	566	566
R^2	0.881	0.88	0.881

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Also, standard errors are mentioned in the parentheses.*

Table 39. Results of interaction of COVID-19 lockdown variable with socioeconomic and demographic variables between January to March 2021

	ln number of solar installations January - March 2021			
	(1)	(2)	(3)	(4)
ln average installations for 2018 & 2019 January - March	0.641***	0.707***	0.641***	0.638***
	-0.0428	-0.0398	-0.0425	-0.0422
Number of cases during January - March 2021	-6737.8	-17.03	-2123	2398.5
	-8869.2	-8159.5	-8242.8	-9124.9
SRES Subsidy Zone	0.285	0.361*	0.300*	0.320*

	-0.157	-0.162	-0.152	-0.151
Age 35 - 54	-0.0213	-0.0306	-0.0327	-0.0163
	-0.0651	-0.0685	-0.0661	-0.0653
Age 55 and over	0.0655	0.0181	0.043	0.0283
	-0.0797	-0.0859	-0.0816	-0.0749
Gender	0.0385	0.0669	0.0315	0.0473
	-0.05	-0.0521	-0.05	-0.0506
University Education	0.132*	0.140*	0.127	0.0919
	-0.0659	-0.068	-0.0665	-0.0621
High-School Education	-0.102	-0.128	-0.117	-0.129
	-0.0749	-0.079	-0.0762	-0.0766
Low income households	0.0553	0.0257	0.0398	0.0535
	-0.0635	-0.0649	-0.0623	-0.0624
Middle income households	0.0738	0.0631	0.0973	0.108
	-0.0737	-0.0783	-0.0733	-0.0721
High income household	0.0345	0.0672	0.0429	0.11
	-0.0601	-0.0611	-0.0602	-0.0598
Married	0.0678	0.0221	0.0481	0.0411
	-0.0549	-0.0554	-0.0554	-0.0552
One or less bedrooms household	-0.0891	-0.0776	-0.0839	
	-0.0582	-0.0616	-0.0582	
Two bedrooms household	0.0383	0.0625	0.0359	
	-0.0668	-0.0652	-0.0659	
Three or more bedrooms household	0.253**	0.283***	0.282***	
	-0.0768	-0.0795	-0.0809	
Owners	-0.0853	-0.131	-0.0915	
	-0.073	-0.0756	-0.073	
Owners with mortgage	-0.0499	-0.101	0.21	-0.0192
	-0.0644	-0.0661	-0.115	-0.0586
Separate houses	0.00283	-0.0129	0.0135	0.021
	-0.0712	-0.0728	-0.0711	-0.0715
Duplexes	-0.0455	-0.00584	-0.0627	-0.0357
	-0.0613	-0.0643	-0.0612	-0.0632
Two or less persons household	-0.446***		-0.449***	-0.468***
	-0.0724		-0.0723	-0.0737
Six persons household	-0.111		-0.119	-0.116
	-0.0742		-0.0892	-0.0885
Four persons household	0.121		0.000397	-0.00915
	-0.0687		-0.0909	-0.0864
Eight or more persons household	0.168**		0.151*	0.158*

	-0.0618		-0.0622	-0.0627
Population	0.0000173***	0.0000204***	0.0000172***	0.0000179***
	-0.00000262	-0.0000031	-0.00000258	-0.00000273
COVID*Number of children	-0.0397*			
	-0.0171			
Number of children	0.330**			
	-0.117			
COVID	-0.0188	-0.0113	-0.0107	0.00695
	-0.0161	-0.0173	-0.0171	-0.017
COVID*Number of persons		-0.0637**		
		-0.0193		
Number of persons		0.422**		
		-0.137		
One child family		0.0931	0.0523	0.0618
		-0.0802	-0.0828	-0.0802
Two children family		0.128	0.162	0.175*
		-0.0767	-0.0883	-0.0856
Three or more children family		-0.0252	0.0247	0.0463
		-0.0781	-0.0876	-0.0891
COVID*Owners with mortgage			-0.0435*	
			-0.0172	
Number of bedrooms				0.621***
				-0.137
COVID*Number of bedrooms				-0.0717***
				-0.0183
Number of observations	559	559	559	559
R^2	0.868	0.86	0.869	0.867

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Also, standard errors are mentioned in the parentheses.*

Table 40.Results of interaction of COVID-19 lockdown variable with socioeconomic and demographic variables between April to June 2021

	ln number of solar installations April - June 2021	
	(1)	(2)
ln average installations for 2018 & 2019 April - June	0.742***	0.705***
	(0.032)	(0.035)
Number of cases during April - June 2021	-14335.4*	-13464.8**

	(5572.9)	(4931.4)
SRES Subsidy Zone	0.109	0.0739
	(0.114)	(0.112)
Age 35 - 54	-0.113	-0.113
	(0.066)	(0.064)
Age 55 and over	0.00902	0.0124
	(0.069)	(0.069)
Gender	0.0545	0.0324
	(0.048)	(0.048)
University Education	0.129*	0.117*
	(0.059)	(0.058)
High-School Education	0.0412	0.0365
	(0.07)	(0.069)
Low income households	-0.0581	-0.0482
	(0.057)	(0.056)
Middle income households	0.0679	0.0884
	(0.071)	(0.07)
High income household	-0.123	-0.0933
	(0.068)	(0.065)
Married	0.105	0.135*
	(0.059)	(0.059)
One or less bedrooms household	-0.0684	-0.0767
	(0.059)	(0.058)
Two bedrooms household	0.0686	0.0633
	(0.059)	(0.06)
Three or more bedrooms household	0.0554	0.0565
	(0.069)	(0.069)
Owners	-0.193**	-0.165**
	(0.065)	(0.064)
Owners with mortgage	-0.106	0.191
	(0.07)	(0.117)
Separate houses	-0.0184	-0.0215
	(0.07)	(0.071)
Duplexes	0.123*	0.0763
	(0.06)	(0.058)
COVID*Number of persons	-0.0404*	
	(0.018)	
Number of persons	0.342*	
	(0.134)	

Population	0.0000154***	0.0000134***
	(0.)	(0.)
One child family	0.108	0.103
	(0.075)	(0.074)
Two children family	0.0793	0.230*
	(0.078)	(0.1)
Three or more children family	0.127	0.109
	(0.067)	(0.071)
COVID	0.00741	0.0138
	(0.016)	(0.016)
COVID*Owners with mortgage		-0.0405*
		(0.017)
Two or less persons household		-0.280***
		(0.066)
Six persons household		0.0703
		(0.069)
Four persons household		-0.182
		(0.106)
Eight or more persons household		0.0612
		(0.057)
Number of observations	565	565
R^2	0.85	0.856

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Also, standard errors are mentioned in the parentheses.*

Table 41. Results of interaction of COVID-19 lockdown variable with socioeconomic and demographic variables during second lockdown 2021

	ln number of solar July - September 2021			
	(1)	(2)	(3)	(4)
ln average installations for 2018 & 2019 July - September	0.708***	0.727***	0.735***	0.729***
	(0.042)	(0.042)	(0.041)	(0.041)
Number of cases during July - September 2021	422.3	444.4	471	270.6
	(236.6)	(240.9)	(240.6)	(213.1)
SRES Subsidy Zone	-0.095	-0.0929	-0.0671	-0.115
	(0.165)	(0.171)	(0.169)	(0.169)
Age 35 - 54	0.0579	0.0464	0.0571	0.03

	(0.073)	(0.073)	(0.072)	(0.073)
Age 55 and over	0.0871	0.0901	0.0815	0.0668
	(0.072)	(0.072)	(0.071)	(0.072)
Gender	0.107	0.102	0.0904	0.0869
	(0.06)	(0.061)	(0.06)	(0.061)
University Education	0.144*	0.148*	0.146*	0.161*
	(0.062)	(0.063)	(0.063)	(0.064)
High-School Education	-0.117	-0.124	-0.137	-0.147*
	(0.069)	(0.071)	(0.071)	(0.072)
Low income households	-0.0228	-0.0351	-0.0283	-0.0464
	(0.059)	(0.059)	(0.059)	(0.06)
Middle income households	-0.00835	-0.0215	-0.0121	0.00232
	(0.083)	(0.084)	(0.083)	(0.085)
High income household	-0.0515	-0.0354	-0.0203	-0.0254
	(0.066)	(0.065)	(0.066)	(0.065)
Married	0.102	0.081	0.0942	0.071
	(0.063)	(0.063)	(0.063)	(0.062)
One or less bedrooms household	-0.0529	-0.0589	-0.0537	-0.0677
	(0.06)	(0.06)	(0.061)	(0.062)
Two bedrooms household	0.00188	-0.0185	0.00364	0.00587
	(0.058)	(0.058)	(0.058)	(0.058)
Three or more bedrooms household	0.0731	0.0772	0.0721	0.109
	(0.073)	(0.074)	(0.074)	(0.076)
Owners	-0.0408	-0.0315	0.302*	-0.0586
	(0.067)	(0.068)	(0.129)	(0.068)
Owners with mortgage	-0.0825	-0.0771	-0.0865	0.149
	(0.067)	(0.069)	(0.067)	(0.132)
Separate houses	0.363**	-0.112	-0.106	-0.129
	(0.12)	(0.076)	(0.075)	(0.073)
COVID*Separate houses	-0.0700***			
	(0.018)			
Duplexes	-0.00337	-0.237*	-0.00603	-0.0055
	(0.062)	(0.12)	(0.063)	(0.063)
Two or less persons household	-0.244***	-0.212**	-0.209**	-0.228**
	(0.073)	(0.073)	(0.073)	(0.073)

Six persons household	-0.069	-0.0773	-0.0884	-0.0969
	(0.073)	(0.073)	(0.072)	(0.076)
Four persons household	-0.0898	-0.0987	-0.103	-0.0901
	(0.11)	(0.111)	(0.11)	(0.11)
Eight or more persons household	0.157**	0.150*	0.144*	0.152**
	(0.058)	(0.059)	(0.058)	(0.058)
Population	0.0000115***	0.0000113***	0.0000117***	0.0000108***
	(0.)	(0.)	(0.)	(0.)
One child family	-0.00177	0.0053	0.0101	-0.00188
	(0.078)	(0.079)	(0.079)	(0.079)
Two children family	0.274**	0.274**	0.261*	0.293**
	(0.101)	(0.101)	(0.102)	(0.101)
Three or more children family	-0.0347	-0.0391	-0.0529	-0.0439
	(0.072)	(0.072)	(0.072)	(0.076)
COVID	0.0621***	0.00778	0.0525**	0.0460*
	(0.017)	(0.017)	(0.018)	(0.02)
COVID*Duplexes		0.0365*		
		(0.018)		
COVID*Owners			-0.0504**	
			(0.019)	
COVID*Owners with mortgage				-0.0379*
				(0.019)
Number of observations	564	564	564	564
R^2	0.845	0.843	0.844	0.842

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Also, standard errors are mentioned in the parentheses.*

Table 42. Results of interaction of COVID-19 lockdown variable with socioeconomic and demographic variables during second lockdown 2021

ln number of solar July - September 2021				
	(1)	(2)	(3)	(4)
ln average installations for 2018 & 2019 July - September	0.729***	0.733***	0.740***	0.723***
	(0.041)	(0.04)	(0.041)	(0.04)
Number of cases during July - September 2021	264.5	274	431.2	441.2
	(208.8)	(208.)	(245.3)	(242.5)
SRES Subsidy Zone	-0.108	-0.0854	-0.103	-0.108

	(0.169)	(0.171)	(0.172)	(0.169)
Age 35 - 54	0.0273	0.0318	-0.255	0.0612
	(0.074)	(0.074)	(0.132)	(0.072)
Age 55 and over	0.0818	0.380**	0.0944	0.0677
	(0.073)	(0.131)	(0.072)	(0.066)
Gender	0.0928	0.0877	0.104	0.0991
	(0.061)	(0.061)	(0.06)	(0.059)
University Education	0.140*	0.149*	0.159*	0.138*
	(0.063)	(0.063)	(0.063)	(0.06)
High-School Education	-0.471**	-0.129	-0.127	-0.142*
	(0.173)	(0.07)	(0.071)	(0.07)
Low income households	-0.036	-0.0302	-0.0388	-0.0373
	(0.06)	(0.06)	(0.06)	(0.059)
Middle income households	-0.0166	-0.00654	-0.0379	-0.00179
	(0.086)	(0.085)	(0.084)	(0.084)
High income household	-0.0462	-0.0452	-0.0447	0.0336
	(0.066)	(0.065)	(0.065)	(0.064)
Married	0.083	0.0849	0.0975	0.0873
	(0.063)	(0.063)	(0.063)	(0.062)
One or less bedrooms household	-0.0503	-0.0564	-0.0586	
	(0.061)	(0.062)	(0.061)	
Two bedrooms household	0.000723	0.0083	0.00182	
	(0.058)	(0.058)	(0.058)	
Three or more bedrooms household	0.0972	0.0832	0.0835	
	(0.075)	(0.074)	(0.073)	
Owners	-0.0372	-0.0395	-0.0399	
	(0.069)	(0.07)	(0.068)	
Owners with mortgage	-0.0876	-0.104	-0.0881	-0.0865
	(0.068)	(0.067)	(0.067)	(0.066)
Separate houses	-0.131	-0.112	-0.122	-0.116
	(0.073)	(0.073)	(0.074)	(0.071)
Duplexes	0.00635	0.00518	-0.00878	0.00435
	(0.063)	(0.062)	(0.062)	(0.062)
Two or less persons household	-0.221**	-0.224**	-0.212**	-0.235**
	(0.074)	(0.073)	(0.072)	(0.072)
Six persons household	-0.0819	-0.0894	-0.0887	-0.0889
	(0.075)	(0.075)	(0.072)	(0.069)

Four persons household	-0.101	-0.108	-0.0933	-0.0948
	(0.112)	(0.113)	(0.112)	(0.109)
Eight or more persons household	0.171**	0.159**	0.153**	0.142*
	(0.058)	(0.058)	(0.058)	(0.056)
Population	0.0000110***	0.0000108***	0.0000109***	0.0000116***
	(0.)	(0.)	(0.)	(0.)
One child family	0.011	0.0143	0.0154	-0.014
	(0.08)	(0.079)	(0.078)	(0.076)
Two children family	0.283**	0.285**	0.253*	0.293**
	(0.1)	(0.102)	(0.102)	(0.1)
Three or more children family	-0.0294	-0.0286	-0.0221	-0.0363
	(0.075)	(0.075)	(0.073)	(0.077)
COVID*High-School Education	0.0491*			
	(0.025)			
COVID	-0.00223	0.0535**	0.00494	0.0637***
	(0.019)	(0.02)	(0.018)	(0.018)
COVID*Age 55 and over		-0.0495*		
		(0.021)		
COVID*Age 35 - 54			0.0442*	
			(0.02)	
Number of bedrooms				0.496***
				(0.138)
COVID*Number of bedrooms				-0.0655***
				(0.018)
Number of observations	564	564	564	564
R^2	0.842	0.842	0.844	0.845

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Also, standard errors are mentioned in the parentheses.*

Table 43. Results of interaction of COVID-19 lockdown variable with socioeconomic and demographic variable after second lockdown

	ln number of solar September - November 2021		
	(1)	(2)	(3)
ln average installations for 2018 & 2019 September - November	0.733***	0.727***	0.729***

	(0.038)	(0.038)	(0.038)
Number of cases during September - November 2021	192.6	249	220.7
	(120.)	(127.5)	(122.3)
SRES Subsidy Zone	0.448**	0.414**	0.452**
	(0.141)	(0.143)	(0.142)
Age 35 - 54	-0.0881	-0.0762	-0.0982
	(0.072)	(0.072)	(0.072)
Age 55 and over	0.0391	0.0167	0.0294
	(0.075)	(0.068)	(0.074)
Gender	-0.089	0.212***	0.229***
	(0.126)	(0.052)	(0.053)
University Education	0.128*	0.145*	0.159**
	(0.061)	(0.057)	(0.059)
High-School Education	-0.0359	-0.0513	-0.0405
	(0.065)	(0.065)	(0.065)
Low income households	0.0644	0.0664	0.0764
	(0.058)	(0.058)	(0.058)
Middle income households	-0.0201	-0.0078	-0.00877
	(0.069)	(0.07)	(0.069)
High income household	-0.0893	-0.0401	-0.0807
	(0.066)	(0.067)	(0.066)
Married	0.0922	0.0946	0.0874
	(0.059)	(0.057)	(0.059)
One or less bedrooms household	-0.106		-0.103
	(0.065)		(0.065)
Two bedrooms household	-0.125*		-0.108
	(0.056)		(0.056)
Three or more bedrooms household	-0.0956		-0.0838
	(0.073)		(0.072)
Owners	0.0127	0.0126	
	(0.066)	(0.065)	
Owners with mortgage	0.0279	-0.0305	0.0287
	(0.069)	(0.065)	(0.069)
Separate houses	-0.0592	-0.0245	-0.0384
	(0.061)	(0.06)	(0.063)
Duplexes	-0.0149	-0.00123	-0.305*
	(0.059)	(0.058)	(0.131)

Two or less persons household	-0.235***	-0.230***	-0.228**
	(0.069)	(0.068)	(0.069)
Six persons household	0.0386	0.0276	0.0512
	(0.064)	(0.064)	(0.065)
Four persons household	0.104	0.0941	0.096
	(0.117)	(0.117)	(0.116)
Eight or more persons household	0.0874	0.0791	0.0954
	(0.056)	(0.055)	(0.056)
Population	0.0000115***	0.0000123***	0.0000119***
	-0.00000225	-0.00000225	-0.00000227
One child family	0.0783	0.0642	0.0697
	(0.083)	(0.082)	(0.083)
Two children family	0.0702	0.072	0.0629
	(0.121)	(0.12)	(0.12)
Three or more children family	-0.016	-0.0364	-0.0129
	(0.062)	(0.067)	(0.063)
COVID*Gender	0.0487*		
	(0.019)		
COVID	-0.0502*	0.00406	-0.0483*
	(0.021)	(0.016)	(0.02)
Number of bedrooms		0.435**	
		(0.143)	
COVID*Number of bedrooms		-0.0469*	
		(0.019)	
COVID*Duplexes			0.0455*
			(0.02)
Number of observations	563	563	563
R^2	0.867	0.865	0.866

*Note ***, **, * represents statistical significance of the coefficient at level 1%, 5% and 10. Also, standard errors are mentioned in the parentheses.*

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