Transition towards Solar-Powered built environment: spatial distributions and impacting factors of Australian solar installations

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Abstract. With the advantages of non-renewable energy conservation and environmental protection, solar energy technology has been widely used worldwide. Data shows that solar systems has been increasingly installed from 2006 to 2016 in Australia. However, impacting factors on Australian solar system installation remain unknown. Therefore, this paper provides a spatial regression analysis to identify the factors that influence households to install the solar panels. Solar installation maps of 2006, 2011, and 2016 are compared to investigate the changes and development of solar distribution. Besides, cluster maps are analyzed to investigate the cluster area distributions. Through analyzing statistical variables such as regression coefficient, p-value, z-value, and Moran’s I value, it can be concluded that educational qualification, population, and household composition have substantial positive relevancies to the installation of solar systems. It also shows that the low solar installation cluster areas mainly distribute at the center of Australia.

Keywords. Solar power, solar energy, solar panel, Australia, spatial regression analysis, spatial distribution.

1. Introduction
The importance of adopting renewable energy technologies is growing rapidly for a sustainable future [8]. With the negative ecological impact of fossil energy, a severe contradiction among energy, environment and economy emerged due to the urgent energy requirement that the world is facing [12]. Therefore, renewable energy technology has been developed and widely adopted because of its higher energy efficiency, eco-friendliness and cost-saving features. According to Zhang et al. (2009), renewable energy can be referred to as the energy types that are recyclable and have little negative environmental impacts [12]. It contains solar energy, wind energy, biomass energy, small hydropower, geothermal energy and ocean energy. In Australia, the annual solar radiation is claimed to be approximately 10,000 times the annual energy consumption of the whole of Australia [4], and this provides favorable
conditions for developing the usage of solar power.

According to the Australian Government, the postcode data for small-scale solar installation of 2006, 2011 and 2016 shows that solar panel has been more commonly used. Chapman et al. (2016) claimed that due to the residential solar photovoltaics (PV) policy announced by the Australian government, the rapidly increased PV installation provided a huge amount of job positions across Australia between 2008 and 2012 [6]. Moreover, the solar installation price was reduced from $15 per watt in 2004 to a lower cost of $3 per watt in 2012. Meanwhile, the motivations for people to adopt residential solar electric technology also need to be considered. Schelly (2014) identified that motivations for adopting renewable energy technology are not only from environmental and economic aspects but also from the consideration of the expected lifestyle, household conditions as well as information communities [9].

However, the impacting factors of solar installation in Australia remain unknown. This paper focuses on the factors that may influence people to adopt residential solar technology across Australia based on the previous research. To identify the impacting factors of solar installation in Australia, a spatial regression analysis software named Geoda is applied on the Australian census data of 2006, 2011 and 2016. Results including impacting factors and the spatial distribution of solar installation are presented. It is expected that the solar installation shows a proportional relationship to the household population and personal qualification of people in economic and education aspects. Low-installation areas are found to cluster at the center of Australia.

2. Methodology

2.1. Data Collection

According to the aim of the research, the data required to be collected contains:

- Census data of 2006, 2011 and 2016
- Solar installation data of 2006, 2011 and 2016
- Australia postal area shapefile

Census data was downloaded from the Australian Bureau of Statistics (ABS) website. The corresponding solar installation datasets for the three specific years were downloaded from the Australian Government Clean Energy Regulator website. Besides, to reduce the error of spatial regression analysis, the Postal Areas ASGS Ed 2016 Digital Boundaries in ESRI Shapefile Format downloaded from the ABS website was used for all years. The raw datasets can then be cleaned and processed for the preparation of the spatial regression analysis.

2.2. Data Cleaning and Processing

Due to the content and order differences between postal area code and postcode, datasets need to be reordered for matching. Data order of shapefile was considered to be the standard. The missing postcode areas were added to the dataset with 0 solar system installation. Several important features were created as independent variables, which have been listed below:

- Percentage of males in the total population
- Percentage of people aged from 20 to 59 in all age groups
- Percentage of highly educated people in the total population (In this study, highly educated people is defined as people with at least a Bachelor degree)
- Percentage of married people in the total population
- Percentage of separated house in all dwelling types
- Percentage of families with high income in all families (According to Australian Bureau of Statistics (2021), the minimum high income (weekly) in 2015-2016 is $2083, $2036 in 2011-2012 and $1711 in 2005-2006 [3]. The statistics may not be accurate enough as only upper-income intervals were considered)
• Percentage of owned house in all tenure types
• Percentage of one family household in all households
• Percentage of households with more than 4 people in all households
• Percentage of households with high income in all households (Same standard as family income)

2.3. Data Analysis
To start with the Geoda analysis, weight files should be created first. According to Anselin (2020), spatial weights are a crucial element when constructing spatial autocorrelation statistics [2]. Besides, the quality of spatial data sources critically contributes to the construction of spatial weights. In this research, queen contiguity, which is better for disposing of potential inaccuracies in polygon files, was selected to create weight files.

With valid weight files, spatial regression analysis can be processed. Total Solar Installation Number was chosen as a dependent variable. Impacting factors for solar installation are aimed to be first analyzed. It is claimed that the regression coefficient represents the relationship between independent and dependent variables. According to Storey and Tibshirani (2003), an independent variable with a \( p \)-value less than 0.05 would be traditionally considered statistically significant [10]. Therefore, an independent variable with a positive regression coefficient and a \( p \)-value less than 0.05 would be considered a statistically significant factor proportional to solar installation. The solar installation distribution maps of the three specific years were compared to investigate the regional development of solar energy in Australia. Besides, to investigate the spatial clusters, Moran’s I value and the associated \( p \)-value (statistical significance) and were mainly studied. A large positive Moran’s I value indicates the studied location has similarly low or high values with the surrounding areas so that the areas are spatial clusters. For instance, high-high clusters, which can be considered as "regional hotspots", indicate that the studied location has high values in a high-value neighborhood [11]. Besides, Hazra (2017) claims that the \( z \)-scores of 1.65, 1.96 and 2.58 correspond to 90%, 95% and 99% confidence intervals, which also correlate with \( p \)-values of 0.1, 0.05 and 0.01 respectively [7]. This indicates that if the output \( z \)-score is larger than 2.58 and \( p \)-value is less than 0.01, the results should be fairly confident.

3. Results and Discussion

3.1. Impact Factors
Table 1 below demonstrates the variables significantly correlated with the solar installation, considering the regression coefficients and \( p \)-value of the independent variables. The variables including highly educated people, separated house, families with high income, one-family household and population in dwellings are notated as High_Edu, Sep_House, H_in_fam, 1fam_house and Dwe_pop correspondingly in Table 1. According to Table 1, the proportional variables are different between years. However, connections between the listed independent variables can still be identified. It can be summarized that the solar installation is mainly proportional to the factors including population, high education level and household combination. Variables such as the percentages of males and families with high-income levels are not significant.

| Table 1. Proportional Variables to Solar Installation for each year. |
|---------------------------------------------------------------|
| **2006**                                                     |
| Variable | % | Population | Male | High_Edu | Sep_House |
|----------|---|------------|------|----------|-----------|
|          |   |            |      |          |           |

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3.2. Spatial Distribution Analysis

Figure 1 shows the total solar installation maps for 2006, 2011 and 2016. Increasingly darker orange is used to indicate the increasing solar installation amount. Based on the comparison of the three maps, a noticeable increase in solar installations at coastal areas can be identified. In 2006, solar installation areas were relatively well-distributed. Installation amount differences between the inland to coastal areas are not obvious. However, solar installation difference has become wider in 2011 and 2016. Colors for inland Australia slowly changes over time, while most coastal areas grow to dark orange that indicates high solar installation amount.

### Table 1. Coefficients and p-values

| Year | Variable % | Coefficient | p-value |
|------|------------|-------------|---------|
| 2011 | Population | 0.0066      | 0.00000 |
|      | H_in_fam  | 6.08926     | 0.00682 |
|      | Own_House | 1.01179     | 0.04102 |
|      | Ifam_house| 3.37029     | 0.00001 |
| 2016 | High_Edu  | 4.73137     | 0.00000 |
|      | Dwe_pop   | -           | -       |
|      | Coefficient| 2.31155    | 0.02559 |
|      | p-value    | -           | -       |

Statistical values including Moran's I value, p-values and z-values of the years from Geoda have been shown in Table 2. Cluster maps with color differentiation are shown in Figure 2 for spatial cluster...
analysis. According to Anselin (2020), bright-colored areas, which are High-High and Low-Low areas, are considered clusters, while the shallow-colored areas represent spatial outliers [2]. Therefore, the highly solar-installed cluster area in 2006 mostly lays close to the edge of Australia, such as north Australia and east Australia, while the low solar-installed cluster areas of 2011 and 2016 mainly located at the center. Considering the migration movements and urban development in Australia, the presented result is considered rational.

| Year | Moran's I | P     | z     |
|------|-----------|-------|-------|
| 2006 | 0.312     | 0.001 | 25.9167 |
| 2011 | 0.254     | 0.001 | 19.7354 |
| 2016 | 0.135     | 0.001 | 10.8494 |

**Table 2.** Statistical Values of Different Years.

![Cluster Map of 2006, 2011 and 2016.](image)

**Figure 2.** Cluster Map of 2006, 2011 and 2016.

### 4. Conclusion

After the spatial regression analysis of the 3-year census data, it can be identified that the statistically significant independent variables are different between years. In conclusion, personal qualifications,
population and household composition are the three main factors that are proportional to the solar installation. Besides, the spatial cluster analysis shows that the cluster areas (Low-Low) aggregate to the center of Australia. In addition, by comparing the solar installation increases between inland and coastal areas of Australia, geographic location is determined to have a strong association with solar energy use. This study provides an important reference for future policy making regarding regional solar installations and incentives.

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